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Collection of Real-time, Multichannel EEG Data From Helicopter Pilots in Flight: A Feasibility Study

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An initial assessment of whether valid electroencephalographic (EEG) data could be collected on helicopter pilots in flight was conducted using 20 volunteers. Each subject provided a brief eyes-open and eyes-closed EEG in the laboratory and then in a helicopter. During helicopter flights, data were monitored and recorded on the ground in real-time via a radio telemetry system. Initial hardware problems resulted in the exclusion of several records, but these problems were resolved toward the end of the study. Analysis of the remaining acceptable EEG records indicated that the typical increase in alpha activity (7.5-13.0 Hz) due to eye closure was clearly observable at every analyzed electrode site regardless of whether the testing occurred in the laboratory or in the helicopter. Further examinations of delta, theta, and beta bands showed that the EEG data were not overly contaminated by artifacts, although it was much more difficult to find "clean" segments on records collected in the helicopter than in the laboratory. It was concluded that it is possible to record and telemeter useable EEG from the in-flight helicopter environment. Follow-on (continued)

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19. Abstract (Continued)

studies will examine the feasibility of analyzing EEG data collected while the pilot is performing flight-related tasks.

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Background

Military relevance

Military commanders frequently are faced with the possibility of requiring aviators to perform their duties for extended durations under less than optimal conditions. Often it is not possible for personnel to receive "time off" from their operational tasks in order to ensure that they are well rested and ready to perform their duties at peak efficiency. Particularly during periods of high workload or during combat scenarios, pilots often face the requirement to conduct flight operations for daily periods that extend beyond a normal 8-hour duty period.

In addition, there are scenarios in which aviators, while not being required to work excessive numbers of hours, are expected to perform effectively under very stressful flight conditions. For instance, a pilot may be expected to continue a flight under the influence of a chemical defense antidote or pretreatment which may compromise judgment and alertness. Also, under emergency situations in which one or more aircraft systems have failed, aviators may be subjected to a variety of factors which will increase substantially cockpit workload.

Thus, a frequent concern centers around how to make decisions about whether personnel safety or mission effectiveness are being compromised because of mental fatigue, physical fatigue, or any other factor. The status of aviators is evaluated by both commanders and physicians while the aviator is still on the ground and "go" or "no-go" decisions are made about each individual. However, the aviators themselves are required to make these decisions once in flight. It is here that the possibility of error is increased because one is relying upon a person whose judgment already may be impaired (as a function of stress or fatigue) to make a judgement about the extent of his own impairment.

As a result of these difficulties, both the operational community and the medical community have expressed interest in the development and validation of more objective measures of aviator status which can be used as an adjunct in making important decisions about crew endurance and crew safety. It would be especially desirable to identify measures which can be implemented in the actual flight environment.

Assessment methodologies

Numerous ideas about making individual status assessments exist. One popular approach has been to utilize either paper-and-pencil or computerized cognitive tests which assess various mechanisms of human information processing (AGARD, 1989). The assumption is that anything which affects these basic mechanisms will produce an effect on tasks where such functions or mechanisms are required. The results from cognitive tests are used to predict operational performance problems as a function of stress or fatigue.

Another approach emphasizes the use of job-related performance assessments such as the measurement of a pilot's ability to control an aircraft or simulator (Dellinger, Taylor, and Richardson, 1986; Simmons et al., 1989; Lees and Ellingstad, 1990; Caldwell et al., 1991). In this case, actual performance on specific job skills is measured (i.e., ability to control air speed and altitude), and the result is used to predict operational performance problems.

Unfortunately, these approaches to assessing the potential for performance decrements are limited in at least two respects. First, with regard to the cognitive assessments, it is often not possible to safely interrupt primary task performance (i.e., flying the aircraft) in order to administer any type of test. Thus, these types of assessments can only be conducted before or after the performance period (i.e., a flight), and this introduces problems with the timeliness and validity of the assessments. Secondly, with regard to the on-task performance assessments (measuring flight skill), it is often difficult for a computerized device to determine whether observed performance fluctuations are unacceptable or not. There are situations in which rapid altitude or heading changes may be required in order to ensure mission accomplishment or survival, but a computer may interpret these rapid changes as indicative of an impaired pilot. Thus, in order for such assessment schemes to work as intended, there must be a concurrent assessment of the individual aviator's status.

It is necessary to identify a method for assessing the operational status of individual aviators which overcomes the problems presented above. Specifically, there is need for an approach which: 1) can be conducted during the accomplishment of the operational task (flight); 2) is feasible from an equipment and personnel perspective; and 3) is objective, reliable, and valid. The one measure which appears to be a reasonable candidate is the electroencephalogram (EEG) which directly measures aviator status via assessments of central nervous system activity.

Utility of electroencephalograms

It is well accepted that the changes in cortical neuronal activity reflected in EEG recordings are associated with a variety of cognitive changes which have been theoretically or directly related to performance changes. In general terms, the relationship between EEG activity and mental/behavioral activation is characterized by the tendency for the brain's electrical activity to increase in amplitude and decrease in frequency as activation is reduced. Conversely, this electrical activity decreases in amplitude and synchrony while simultaneously increasing in frequency during heightened alertness (Greenfield and Sternbach, 1972).

Nebylitsyn and Mozgovoy (1973) reported that various aspects of performance on a cognitive test (number of problems solved, time spent on searching for different solutions, etc.) were positively correlated with frontal and occipital energy in the 21-30 Hz range and negatively correlated with energy in the 1-3 Hz range. Petrek (1982) summarized a number of Soviet studies concerning the relationship between EEG and fatigue or performance. Some of the findings were that alpha (8-12 Hz) activity decreased in airmen during prolonged flights, in truck drivers after working 7-hour shifts, and in stenographers after working 6-hour shifts. Other findings were that theta (4-7 Hz) activity is often increased during states of discomfort such as weightlessness, acceleration, and sensory deprivation. In addition, it was observed that theta (4-7 Hz) and delta (1-3 Hz) increased as subjects were exposed to increasing altitude conditions, and these changes in the EEG were accompanied by increases in reaction time, decreases in working ability, deterioration of handwriting, and ultimately loss of consciousness.

Belyavin and Wright (1987) reported that, while EEG changes cannot predict vigilance changes in a straightforward linear fashion, generally there was increased theta and delta activity and decreased beta activity associated with worsening performance during 15 hours of testing. These results are quite consistent with the basic arousal hypothesis which suggests an increase of slow-wave EEG as a function of decreased alertness. Further, consistent evidence has been offered by Pigeau, Heslegrave, and Angus (1987) who found that increased delta and theta activity was associated with increasing levels of sleep deprivation throughout a 64-hour deprivation period. These results have since been supported by Comperatore et al. (1993) who reported increases in theta as a function of sleep deprivation.

Resting EEGs are also sensitive to drug-induced changes in central nervous system activation. Vollmer et al. (1983) reported that the dominant alpha (8-12 Hz) frequency is slowed, the amount of power associated with fast alpha activity is

reduced, and the relative amount of slower theta activity is elevated as a function of even mild drug-induced sedation (produced with ketotifen). Caldwell, Stephens, and Carter (1992) and Pickworth et al. (1990) reported significant increases in delta, tendencies toward increases in theta, and marked reductions in alpha activity as a consequence of atropine administration. These effects were accompanied by behavioral evidence, including self-reports, of increased sedation. Goldstein, Murphree, and Pfeiffer (1968) reported an increase in delta and theta activity, a decrease in alpha, and a slight increase in beta as a function of administering diphenhydramine (an antihistamine with known sedative effects). Fink and Irwin (1979) also found an increase in delta activity and a decrease in alpha under diphenhydramine; however, they also saw a reduction (rather than an elevation) of theta.

All of the above studies present strong evidence for the validity and sensitivity of EEG for describing and/or monitoring the status of humans. However, these investigations were conducted in standard clinical or laboratory settings. Thus, at this point, questions remain about the utility of collecting and analyzing EEG data from aviators who are performing normal flight duties on board actual aircraft.

EEG collected in flight

There have been efforts to collect EEGs during both simulator and actual flights, and to directly relate EEG activity to performance accuracy on operational tasks. Sem-Jacobsen et al. (1959) were probably the first investigators to record EEGs during flight. Their initial feasibility study indicated it was possible to obtain useable 8-channel EEG recordings from both pilots and nonpilots in a T-33 jet during operational flight. From this beginning, Sem-Jacobsen (1961) later was able to report the ability to utilize a combination of in-flight EEG analysis, and in-flight motion pictures to aid in the selection of pilots for high-performance aircraft. Although all of the tested pilots appeared to be fit for duty based on routine examinations, the in-flight tests revealed that some were subject to episodes of high voltage, slow-wave activity during flights. Others actually evidenced major EEG abnormalities which included unconsciousness for 30 seconds. The authors pointed out in a later paper (Sem-Jacobsen and Sem-Jacobsen, 1963) that some of the weaker pilots in this study were retested under high G conditions on a centrifuge. The centrifuge exposure failed to produce similar problems to those seen in the actual aircraft. Sem-Jacobsen used these data to emphasize the importance of assessing pilot functioning during actual flight stress.

Blanc, LaFontaine, and Medvedeff (1966) collected EEG data from Air France captains and copilots in flight between Paris and

Rio de Janeiro. The data, which were recorded on board and analyzed after the flight, showed alpha activity prior to takeoff. During takeoff, the EEG was characterized by reduced alpha and increased beta accompanied by elevated muscle activity. Once at altitude, alpha activity returned only to disappear again during the approach to landing. At one point, the investigators were able to discern an episode of sleep after the captain passed the controls to the copilot. Overall, it was concluded that the EEG traces were of very similar quality to those collected on the ground.

Maulsby (1966) reported successful collection of continuous EEG during the first 2 days of Gemini VII. The data were collected and scored visually to determine the effects of weightlessness on brain activity. A total of 54 hours of data were collected beginning 15 minutes prior to takeoff. The takeoff data were obscured due to excessive muscle artifact; however, after 24 hours in orbit, the EEG evidenced a more relaxed state with little or no EMG artifact. One period, on the first day in which the astronaut attempted to sleep but failed, displayed the expected high levels of alpha activity. One sleep period, which began at approximately 33 hours and lasted for about 8 hours, yielded EEGs of sufficient quality to score in terms of the traditional sleep stages. Adey, Kado, and Walter (1967) later reanalyzed these data with more objective measures and found evidence that theta activity was increased as a function of weightlessness (in comparison to EEGs collected earlier on the ground).

Howitt et al. (1978) reported that, in a single-subject study, EEG activity collected during a series of instrument flights showed sensitivity to changes in workload and fatigue. These investigators reported rather gross increases across a large frequency range (from 4-16 Hz) which apparently occurred concurrently with increased workload. They also reported that the arousal changes under fatigue states were not the same as those observed when the subject was not tired. Wilson et al. (1987) offered further evidence for the utility of using EEG as a measure of arousal/workload during flights. They found that recorded EEG activity reflected workload changes produced by type of flight (whether pilots were flying lead or wing position) and whether the flight was in an aircraft or a simulator.

In terms of predicting flight performance accuracy based upon in-flight EEG activity, a recent report by Sterman et al. (1987) suggests there is a unique pattern of EEG distribution associated with good performance. It was found that central EEG activity displayed significant asymmetries consisting of elevated left hemisphere activity in the 8-15 Hz range during competent performance. This effect was observed both while subjects were flying simulators in the laboratory or they were flying a T-38 travelling at 500 knots at low altitude. Most notably, the

EEG power asymmetry from left to right hemispheres disappeared when subjects performed poorly.

In summary, the majority of research supports the contention that reasonable, interpretable EEG can be collected in flight. In addition, various authors have related successfully changes in observed EEG activity (during flight) to changes in other relevant variables such as workload, fatigue, or the accuracy of performance.

Real-time telemetry of multichannel EEG

Presently, there exists a need to expand upon the work of these earlier researchers in order to maximize the utility of in-flight EEG monitoring for the purposes of predicting or evaluating flight performance decrements. Besides proving that EEG data can be collected from the helicopter environment as opposed to the better-researched fixed-wing environment, two additional refinements appear necessary: 1) rather than relying on only 1-8 channels of EEG, a full 10-20 montage is desirable; and 2) rather than being restricted to posthoc analyses of recorded EEGs, the feasibility of real-time assessments should be explored.

The first refinement (full 10-20 montage) will permit a complete assessment of the brain's electrical activity from every standard recording site. This has the potential of significantly enhancing the sensitivity (and the predictive validity) of EEGs collected in operational settings because activity from the entire cortical surface is being examined. More limited recordings in which only a subset of channels is analyzed could result in a failure to detect noteworthy EEG changes simply because the investigator is unlucky enough to choose the "wrong" recording site. For instance, there is certainly evidence to suggest that the symmetry of EEG activity between the two hemispheres is important, but we know that, in the past, some investigators have been unable to collect symmetry data because of limitations in the number of data channels. Thus, examination of every standard scalp electrode site should minimize the possibility of overlooking an important EEG effect.

The second refinement (real-time acquisition and analysis) will permit a more accurate examination of changes in ongoing EEG because the investigator can monitor the subject from a behavioral, performance, and electrophysiological standpoint concurrently. Thus, any interesting or unusual shift in the amount or distribution of EEG activity has a better possibility of being directly linked to a specific external event.

Objectives

The present investigation expands upon the previous research of other investigators and earlier studies conducted in this Laboratory by establishing the feasibility of real-time telemetry of multichannel EEG from subjects in flight in an Army helicopter. Collected EEG records were inspected visually for the presence of artifact attributable to both subject activity (eye-movements, muscle, etc.) and to interference from electrical equipment onboard the helicopter (radios, instruments, etc.). Afterwards, the power spectra of records collected in the Laboratory were compared to those collected in the helicopter to determine whether there were differential EEG changes as a function of the testing environment.

Methods

Subjects

Ten subjects contributed the data presented in this report. The mean age of these volunteers was 28.1 years with a range of 22-34 years. Nine were male and one was female, and all subjects were qualified Army helicopter pilots who possessed between 159 and 3,000 hours of total flight time.

In total, 20 subjects volunteered for the study, but eight of these were dropped due to equipment malfunctions or failures which prevented suitable data collection, and two were excluded for other technical problems which yielded inadequate amounts of data for analysis.

All participants were fully briefed about the objectives of the research and the procedures to be used, and all were informed of their right to withdraw from participation at any time without penalty. Signed informed consent agreements were obtained from each individual in the sample.

Apparatus

Laboratory EEGs

Laboratory electroencephalographic evaluations were conducted using a standard, commercially available Cadwell Spectrum 32 neurometric analyzer* (see Figure 1). This device was equipped with the standard hardware and software necessary to collect, store, and analyze lengthy EEG records from subjects tested in a typical laboratory environment.

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* See manufacturers' list.

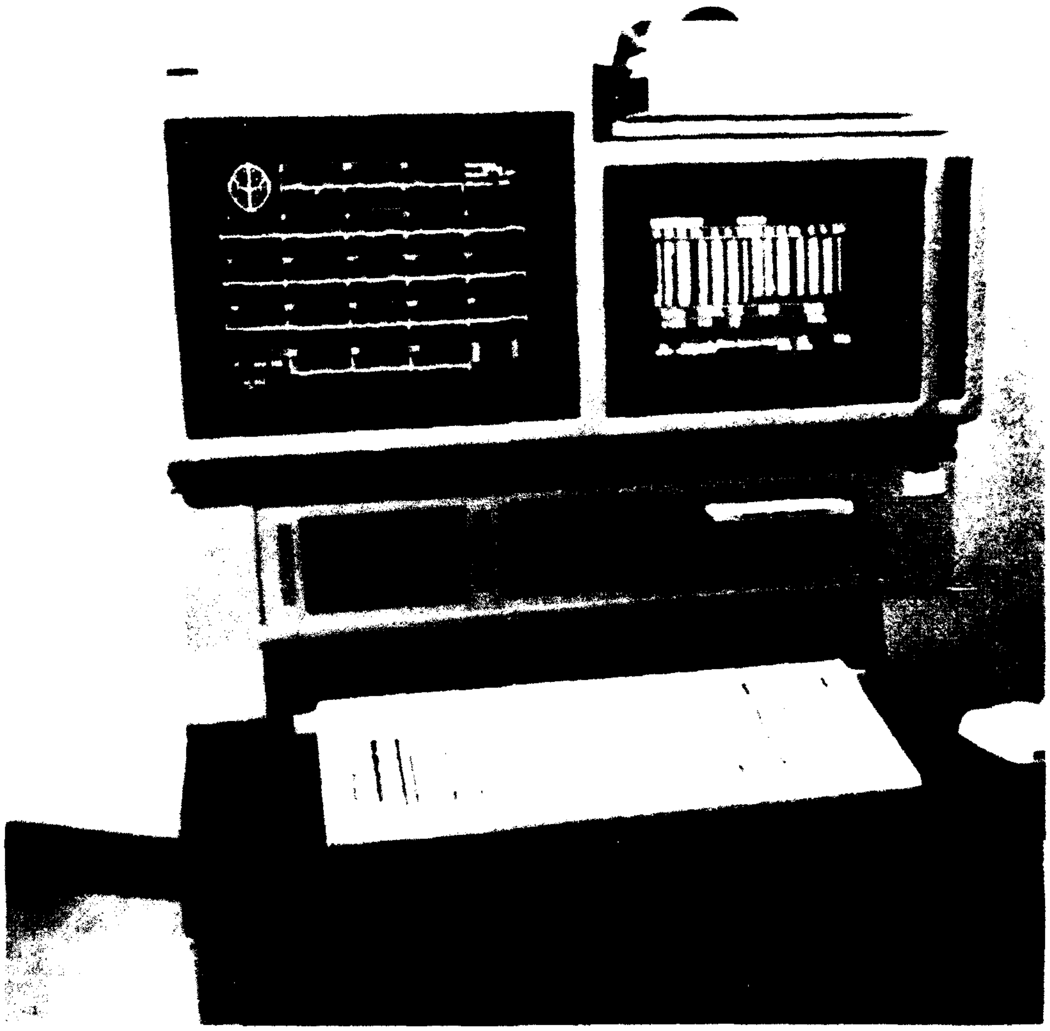

Figure 1. The standard Cadwell Spectrum 32 Neurometric Analyzer.

All data were recorded on optical disks for later review and analyses. The 21 active EEG leads were referenced to electrodes placed on the right and left mastoid processes (A1 and A2). Data were collected with the widest filter settings available on the Spectrum 32 in order not to obscure any useful information discernable from initial visual examinations of the traces or from subsequent power spectral analyses. The high filter was set

at 100 Hz and the low filter was set at 0.53 Hz. The traces (hard-copy displays) were produced with a standard sensitivity of 50 microvolts per centimeter with a paper speed of 30 millimeters per second. Several of these traces are displayed, after substantial reductions, later in this report.

In-flight EEGs

All in-flight electroencephalographic evaluations were conducted using a Cadwell Airborne Spectrum 32* (see Figure 2) which was set to the parameters discussed. This device was mounted in a U.S. Army UH-1 utility helicopter (see Figure 3) where it was interfaced with the telemetry equipment described later.

Figure 2. The specialized Cadwell Airborne Spectrum which interfaces with the Spectrum 32 at the receiving station.

Airborne unit

The Airborne Spectrum 32 uses three microprocessors--one for acquisition, one for data transmission, and one for supervision. Booting the computer at power-up loads all software from a battery-backed RAM-disk board, and puts the system in a mode where it waits for linking and subsequent commands from the ground station Spectrum 32. The unit is shock-mounted in an aluminum cage, which is mounted to the cabin floor behind the pilot's seat (see Figure 4). The overall weight of the unit is approximately 75 pounds. Power comes from the aircraft's 28-volt DC bus.

Figure 3. The U.S. Army UH-1 helicopter in which all in-flight testing was conducted.

Software in the airborne unit is a subset of the standard Spectrum 32 software. It can acquire signals as can the standard unit, but has no graphics display capability. Specialized software handles commands received from the ground station and the transmission of data to it. All the acquired data are placed into a first-in, first-out "ring buffer," where it waits for transmission to the ground unit. This buffer is designed to hold

data during periods where the telemetry radio link is lost, as in steep turns or very low-level flight. Depending on certain factors (such as the number of EEG channels being collected), this buffer can store several minutes of data. For instance, when collecting 19 channels of EEG, 6 minutes of data can be buffered in the event of transmission interruption.

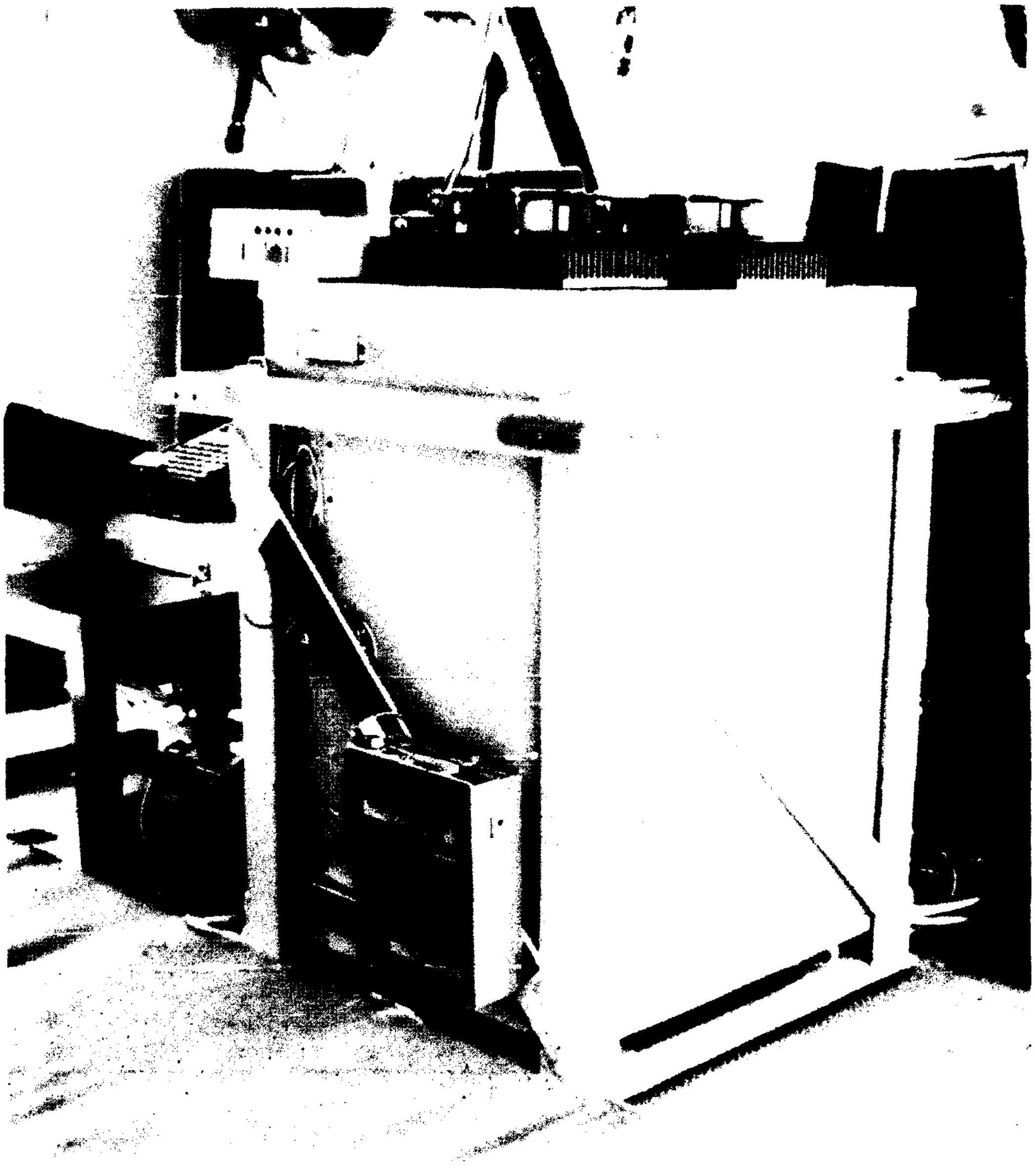

Figure 4. The Cadwell Airborne Spectrum bolted to the floor immediately behind the pilot's seat in the UH-1 helicopter.

Once digitized by the acquisition processor, the EEG data are grouped into blocks by the communications processor for transmission to the ground Spectrum. The signal output from the airborne unit is a serial bit stream at a rate of 100 Khz. This signal is low-pass filtered to reduce the bandwidth requirements of the radio link to approximately 150 Khz. High and low levels, similar to the format used in pulse code modulation telemetry systems, are used to represent digital ones and zeros.

Commands sent up to the airborne unit are also in a digital format, as is the EEG data. The uplink bit rate is somewhat slower, however, at 60 Khz. Received by the telemetry receiver, this serial stream is first routed through the universal asynchronous receiver/transmitter (UART) card of the airborne unit where it is both high- and low-pass filtered, and converted to a parallel form. The communications processor on the link board then buffers these commands until the main processor is ready to execute them.

Ground unit

The ground unit is a standard Cadwell Spectrum 32 which contains the usual Spectrum 32 hardware with two additional circuit boards installed in the computer's backplane. One board, called the UART board, conditions the incoming signal from the receiver, shapes the outgoing signal to the transmitter, and does the serial-to-parallel conversions for both directions. The second board, the link controller, contains the communications processor and buffers, where outgoing data are held until ready for transmission, and incoming data are held until ready for processing by the rest of the system. Incoming EEG data from the aircraft can be displayed on the ground Spectrum's text and graphics monitors and stored on an optical storage disk.

Special software is needed by the ground unit to communicate with the airborne unit. Though much of the unit's software appears similar to that of a normal Spectrum, it has important differences to account for the communication link between the ground and airborne units. The operator still has the same testing features available and can bring up screens for impedance checks, preamplifier calibration, etc. The data display is slightly different from what is normally seen on a standard Spectrum 32. Rather than the typical continuous streams of data, similar to a standard EEG paper trace, the data are presented in 8-second blocks (or one "page" at a time). Data transferred from the airborne unit come in groups of small packets. Integrity is assured by using a checksum scheme and "handshaking" with each data group. For each packet sent by the airborne unit, the ground unit returns an acknowledgement. If a packet is not acknowledged by the ground unit, it is resent. Packets are time-stamped to aid in reconstructing the original data signals.

Commands to be transmitted to the airborne unit are generated by the main processor and handed off to the communications processor on the link board. When ready, the command is converted to a serial stream and low-pass filtered as mentioned above before transmission.

Data signals from the airborne unit are received by the telemetry receiver and are first routed through the UART card of the ground unit where they are both high- and low-pass filtered and converted to a parallel form. The communications processor on the link board then buffers these data until the main processor is ready for display or storage.

Radio link

The telemetry system uses a two-way microwave radio link to send commands from the ground station up to the aircraft ("uplink") and EEG data signals from the aircraft down to the ground station ("downlink"). Operating at 1740 Mhz, the uplink is composed of a transmitter at the ground station, a matching receiver mounted in the aircraft, and one antenna at each location. The downlink, operating at 1820 Mhz, is composed of a transmitter mounted in the aircraft and a matching receiver located at the ground station. It shares the same antennas with the uplink by the use of two diplexers. The ground receiving station is depicted in Figure 5.

The specific components used in the aircraft include a Broadcast Microwave Services (BMS) model TBT-20015SV transmitter* mounted in the right aft compartment, and a BMS portable receiver, model TBR-300*, located in the left aft compartment. Power for the transmitter and receiver units comes from the aircraft 28-volt DC bus through a 10-amp circuit breaker installed in the overhead control panel. A K&L model 4CZ45-1740/NT1820-N/N diplexer* is used to feed the transmitter and receiver cables into a common omni-directional antenna, a BMS model TBA-2-0*, which is mounted to the lower side of the tail boom.

At the ground station, an Anixter Communications Systems model P-1548GN dish antenna* is mounted on a Tecom Industries, model 203011A controller* and model 203009 rotator system*. This azimuth-only system allows the aircraft to be tracked during flight testing. The antenna is connected through a diplexer--as on the aircraft--to the transmitter and receiver. The transmitter and diplexer used at the ground station are identical to those in the aircraft. A Loral Terracom model TCM-601A receiver* provides the downlink data signal to the ground-based Spectrum 32.

This telemetry system proved successful in transmitting and receiving the Spectrum signals over a range of approximately 40 miles when the aircraft was approximately 1000 feet or more above ground level.

Electrodes

Grass silver cup electrodes, placed on subjects' scalps with collodion, were used to detect EEG. These were standard Grass E5SH electrodes used in typical clinical settings. No modifications to the electrodes or wiring were made.

Figure 5. The laboratory-based telemetry station includes a radio transmitter and receiver, antenna tracking controller, oscilloscope, and Cadwell Spectrum 32 equipped with two additional circuit boards.

Procedure

Each subject was tested twice during a single day, and afterwards, the electrodes were removed and he/she was released from the experiment. Subjects were instructed to arrive at the Laboratory early in the morning, at which time 25 scalp placements were marked with a grease pencil according to the International 10-20 system. Each site then was thoroughly cleaned with acetone and electrodes were attached to the scalp with collodion (see Figure 6). Electrodes were filled with electrolyte gel through the small hole in the top. Impedances were reduced to less than 5000 Ohms at each electrode prior to testing.

Once all 25 electrodes had been attached, the subject proceeded to his/her first EEG test which was conducted in the Laboratory. This test period consisted of the subject taking two short cognitive tests administered via a standard desktop computer. This was done in order to give the experimenters time (approximately 5 minutes) to examine the quality of the EEG signals prior to continuing with testing; the cognitive performance data per se were of no interest in this study.

After the subject completed the two cognitive tests, he/she was instructed to sit quietly with eyes open for approximately 3 minutes while EEG data were collected. Next, the subject was instructed to sit with eyes closed for approximately 3 minutes.

Once the resting eyes-open/eyes-closed EEG was complete, the subject was assisted with strapping on his/her standard Army flight helmet for the in-flight portion of the test. The aviator then was escorted to the aircraft.

Upon being seated in the front right seat of the helicopter, the aviator was connected to the airborne unit described earlier. Prior to departing from the helipad in front of the Laboratory, impedances of electrodes and the integrity of the radio link (between laboratory-based and Airborne Spectrum) were checked, and when possible, adjustments were made to guarantee the quality of the data. However, occasionally there were electrode problems that could not be resolved in the aircraft (i.e., an electrode would become detached or the impedance would be slightly above 5000 Ohms).

Following verification of the radio link and the signal integrity, the UH-1 departed the helipad enroute to the area in which several standardized flight maneuvers were conducted. A U.S. Army Aeromedical Research Laboratory (USAARL) safety pilot supervised each flight in the UH-1 (from the front left seat), but the test aviator was required to fly the aircraft throughout the mission, with the exception that he/she would not be "on the controls" during the eyes-open/eyes-closed EEG. Otherwise, the

subject flew all of the specified maneuvers under command from the safety pilot. EEG data were collected continuously throughout each flight, and segments of interest were indicated by event marks placed in the optical EEG record.

The eyes-open/eyes-closed EEG data generally were collected during the first portion of each flight--usually beginning within 5-10 minutes after takeoff. However, the eyes-open/eyes-closed data collection sometimes was repeated at the end of the flight profile (about 1 hour after takeoff) if the quality of the first epochs was not satisfactory for any reason. After departure from the helipad, the safety pilot and the experimenters would remain in voice contact via 2-way radio. The safety pilot would advise the experimenters when it was possible to initiate testing, and the actual time of testing varying somewhat due to air traffic, location over the terrain, and other factors. However, once the safety pilot indicated it was safe to begin the in-flight testing, the experimenter would give the instructions, via radio contact, to begin the eyes-open/eyes-closed portion.

The subject was told that he/she should begin the eyes-open segment by finding a visual fixation point in the aircraft, and that he/she should make every effort to minimize eye-movements and muscle artifacts while the safety pilot flew the aircraft. The eyes-open would begin when the subject was notified by the experimenter or the safety pilot, and the subject was instructed to remain quiet for a period of approximately 3 minutes while data were collected. At the conclusion of this 3-minute period, the subject was instructed to close his/her eyes while continuing to remain as still and relaxed as possible while another 3 minutes of data were collected. The research technician in the rear of the aircraft marked the beginning of each period by pressing a button on the control panel of the airborne Spectrum 32.

After the subject completed the eyes-open/eyes-closed EEG, he/she was given control of the aircraft for the remainder of the flight mission. This latter part of the flight, while not the focus of the present report, consisted of a series of precision maneuvers such as timed straight-and-levels, turns, climbs, and descents. The flight concluded with an instrument landing system (ILS) approach into Cairns Army Airfield, Alabama. During all of these maneuvers, the subject's EEG activity was monitored and recorded in addition to his/her flight performance (these data will be examined in a later report). Following the ILS, the subject was flown back to the Laboratory for electrode removal and release.

Results

EEG data were collected from these helicopter pilots without major complications (at least from the subjects' viewpoints). There were few complaints of discomfort even though subjects wore a standard Army flight helmet on top of the full 10-20 montage of electrodes for periods of more than 1 hour.

Figure 6. A research volunteer outfitted with Grass silver-cup electrodes attached to the scalp with collodion.

There were initially a number of equipment problems which hampered data collection and/or decreased the range of data transmission. However, these were corrected as quickly as the source of the problem was identified. Toward the end of the study, clean data were being successfully transmitted over a distance of up to 40 miles. Even longer data-transmission ranges would have been possible if the flight profile had been flown at higher altitudes.

In terms of the actual data collected, the eyes-closed/eyes-open EEG data from the two testing situations (laboratory and helicopter) were first visually inspected to determine the general quality of the EEG. In order to convey some of the findings in this report, segments of EEG were selected from a designated time point within each subject's record for presentation here. This time point was selected prior to any review of the data, in order to present an objective representation of the results. The optical disk record was first scanned for the event mark indicates the beginning of the eyes-open portion, and one page (8 seconds) of the EEG data recorded approximately 1 minute after the mark was printed. Next, the disk was scanned for the beginning of the eyes-closed portion, and one page of the data recorded approximately 1 minute after that mark was printed. This was accomplished for both the laboratory and in-flight EEG records. These data are depicted in Figures A-1 to A-10 (see Appendix A).

Most of these recordings attest to the high quality of the data gathered when the telemetry system was functioning properly. However, there are some figures that indicate problems that resulted in individual EEG channels or the entire record being excluded from further analysis. For instance, Figure A-2 shows that the Cz electrode became disconnected during the flight, and this resulted in a requirement to treat this single channel of data as missing. However, it was possible to use the other data from the record. Unfortunately, it was not possible to salvage any in-flight data from the record represented by Figure A-10 because of overall poor quality attributable to excessive eye-movement artifact. Furthermore, although the record depicted in Figure A-3 initially appeared to be of sufficient quality for subsequent analysis, it was not possible to obtain a sufficient number of artifact-free epochs to calculate an accurate power spectrum. Thus, this record was excluded as well.

Following the visual inspection of the data presented in Appendix A, each EEG record was recalled and scanned for several suitable epochs upon which power spectral analyses could be performed. Three relatively artifact-free epochs were selected

from each eyes-open and each eyes-closed segment for this analysis. These epochs are illustrated in Figures B-1 to B-8 (see Appendix B).

Once the epochs were selected, they were reduced to a series of absolute power values via Fast Fourier Transform procedures resident in the Cadwell Spectrum 32 software. Data values represented the amount of EEG activity present within the delta (1.5-3.0 Hz), theta (3.0-7.5 Hz), alpha (7.5-13.0 Hz), and beta (13.0-20.0 Hz) bands for each group of three epochs averaged together. The data from the in-flight eyes-open and eyes-closed conditions then were compared to the laboratory eyes-open and eyes-closed conditions using BMDP4V repeated measures analysis of variance. There were two factors in the analysis--the first was environment (in-flight versus laboratory), and the second was condition (eyes open versus eyes closed). Seven representative EEG channels (Fz, Cz, Pz, P3, P4, O1, and O2) were statistically examined for this report. Eight subjects were used in this analysis.

Delta activity

The analysis of the absolute power within the 1.5-3.0 Hz range indicated there was one significant main effect due to the environment factor. At Fz, more "delta" activity was observed in the helicopter than in the laboratory. This was probably attributable to increased eye-movement contamination in the flight records since it was observed only at the frontal site. None of the other channels of EEG data was affected similarly. Also, there were no other main effects or interactions. This was the case for the data recorded at all seven electrode locations. The means are presented in Table 1 and the F values are presented in Table 2.

Theta activity

The examination of the data within the theta range (3.0-7.5 Hz) also revealed effects attributable to whether or not subjects were tested in the helicopter or the laboratory. In this case, there were significant main effects on the environment factor at Cz, Pz, P4, O1, and O2. All of these were attributable to the presence of more theta in the helicopter than in the laboratory. However, there were not significant main effects on the condition factor (eyes-open versus eyes-closed), nor were there any interactions between environment and condition at any of the electrodes examined (see Tables 1 and 2).

Table 1.
Mean power under each environment and condition.

Site/Cond		Delta Flight	Delta Lab	Theta Flight	Theta Lab	Alpha Flight	Alpha Lab	Beta Flight	Beta Lab
Fz	Closed	8.3	5.4*	19.0	18.5	68.1	42.2*	6.5	5.3
	Open	6.0	5.2*	14.8	12.8	15.4	11.3*	4.3	4.2
Cz	Closed	7.4	6.2	20.8	18.2*	80.7	52.4*	9.8	6.8*
	Open	8.6	7.2	17.5	12.6*	17.7	15.5*	5.3	5.1*
Pz	Closed	5.8	5.9	14.0	11.2*	109.9	85.3	10.7	7.5
	Open	6.9	7.2	11.5	9.3*	38.6	52.5	6.2	5.4
P3	Closed	4.6	5.1	10.7	9.2	71.2	54.4	8.3	6.7
	Open	4.8	5.1	8.3	7.2	28.6	27.6	5.2	4.6
P4	Closed	4.8	4.5	11.2	7.8*	70.7	60.4	8.9	6.5
	Open	5.4	4.7	8.8	7.0*	28.0	40.3	5.5	5.1
O1	Closed	5.1	4.3	7.2	5.7*	75.3	61.9*	9.0	5.4*
	Open	3.5	3.7	6.0	3.8*	20.8	14.0*	5.1	3.2*
O2	Closed	3.7	4.8	7.7	5.4*	81.7	66.3	9.3	6.2
	Open	4.3	3.8	7.2	4.4*	25.1	16.7	6.9	4.0

* Denotes a difference between air and ground tests ($p<.05$)

Alpha activity

Analysis of the absolute power of EEG activity between 7.5 and 13.0 Hz again indicated a few effects of the environment factor. There were significant main effects attributable to whether or not the subject was tested in the helicopter or the laboratory at Fz, Cz, and O1--all of which were due to slight elevations in alpha during the in-flight testing. There were also marked changes in the alpha activity at all of these and the remaining sites under the eyes-open and eyes-closed conditions. The analysis revealed significant increases in the amount of alpha activity from eyes-open to eyes-closed at Fz, Cz, Pz, P3, P4, O1, and O2 as can be seen in Table 1. Furthermore, the characteristics of this effect were not altered by whether the subjects were being tested in the helicopter or in the laboratory as evidenced by the absence of an interaction between environment and condition for any electrode (see Table 2).

Table 2.
F values for significant effects in each activity band.

Band	Effect	Site	F value
Delta	Environment	Fz	$F(1,7) = 6.50$, $p<.04$
	Condition	--	--
	Environment x Condition	--	--
Theta	Environment	Cz	$F(1,7)=11.44$, $p<.02$
		Pz	$F(1,7)= 9.36$, $p<.02$
		P4	$F(1,7)=15.41$, $p<.01$
		O1	$F(1,7)= 6.58$, $p<.05$
		O2	$F(1,7)=11.79$, $p<.02$
	Condition	--	--
	Environment x Condition	--	--
Alpha	Environment	Fz	$F(1,7)= 6.59$, $p<.05$
		Cz	$F(1,7)= 5.57$, $p=.05$
		O1	$F(1,7)= 7.84$, $p<.03$
	Condition	Fz	$F(1,7)=22.66$, $p<.01$
		Cz	$F(1,7)=44.06$, $p<.01$
		Pz	$F(1,7)=43.27$, $p<.01$
		P3	$F(1,7)=179.11$, $p<.01$
		P4	$F(1,7)=48.13$, $p<.01$
		O1	$F(1,7)=21.05$, $p<.01$
		O2	$F(1,7)=26.27$, $p<.01$
	Environment x Condition	--	--
Beta	Environment	Cz	$F(1,7)=14.25$, $p<.01$
		O1	$F(1,7)= 7.38$, $p<.03$
	Condition	Fz	$F(1,7)= 6.15$, $p<.05$
		Cz	$F(1,7)=19.20$, $p<.01$
		Pz	$F(1,7)=40.05$, $p<.01$
		P3	$F(1,7)=69.59$, $p<.01$
		P4	$F(1,7)=11.56$, $p<.02$
		O1	$F(1,7)=24.91$, $p<.01$
		O2	$F(1,7)= 7.85$, $p<.03$
	Environment x Condition	--	--

Beta activity

Analysis of beta activity revealed main effects on both factors. The ANOVA indicated there were differences between the two testing environments at both Cz and O1 which were due to increased beta being recorded in the helicopter in comparison to the laboratory. There were also increases in beta under the

eyes-closed versus the eyes-open conditions at every electrode location analyzed--Fz, Cz, Pz, P3, P4, O1, and O2 (see Tables 1 and 2).

Discussion

An examination of the EEG traces from the 10 subjects presented here indicates that, in the majority of cases, the signal quality was not significantly compromised by flight-related artifacts. However, there were in-flight data excluded from this report because of: 1) equipment problems which yielded unusable data, and 2) the presence of sweat and movement artifacts which made the data supplied by some subjects unscorable.

Some equipment problems which essentially resulted in the loss of several subjects' data were anticipated at the outset since this was the first test of the new in-flight telemetry apparatus described here. These problems consisted primarily of either basic hardware failures/irregularities with the Spectrum (due to heat, vibration, and moisture) or radio equipment failures. However, after the initial subjects were tested, the telemetry system was modified to improve overall functioning and reliability. Also, as the research team gained experience with conducting tests in this novel environment, procedural refinements were included to minimize some difficulties. Future investigations will no doubt yield data of higher quality, and this will result in fewer records being identified as unusable.

The problems with subject-related artifact contamination during the flights will be more difficult to solve. Eye movements were frequently evident in the frontal leads, and muscle contamination was found often in the T3/T4 and O1/O2 data. Although the aviators in this study had relinquished control of the helicopter to a safety pilot during the eyes-open/eyes-closed EEG, it was evidently very difficult for them to fully eliminate all eye movements. This is an understandable problem for pilots who have learned through training and experience the importance of constantly scanning their in-flight environments for the presence of safety hazards. In a future study, it might be helpful to spend more time with each subject stressing the importance of minimizing artifacts at the outset of the experiment; however, movement and muscle artifacts will continue to be a problem outside of controlled laboratory settings.

Results from the eight subjects in this study who yielded data of sufficient quality to be statistically compared across the helicopter and laboratory environments were noteworthy. Overall, it appears that the EEGs collected in the helicopter environment were reasonably comparable to EEGs collected in the laboratory.

First, there were no marked changes in delta activity at any of the electrodes with the exception of a slight in-flight elevation at Fz. Although genuine delta activity was not anticipated in normal, alert subjects, this frequency range was examined because it is susceptible to the presence of eye movement contamination. The fact that there were not widespread elevations in delta from the laboratory to the aircraft suggests that the epochs chosen for analysis were not significantly contaminated with eye movements regardless of the situation in which these data were recorded.

Second, there were the expected elevations in alpha activity from eyes-open to eyes-closed, and these were equally detectable in both testing environments. However, there were no interactions between the test environment (in-flight/laboratory) and the testing condition (eyes-open/eyes-closed) at any of the analyzed electrode sites (Fz, Cz, Pz, P3, P4, O1 or O2). These results are encouraging because they suggest that the expected effect of eye closure on the EEG was clearly detectable in a novel environment (the helicopter) as well as under standard laboratory conditions. However, it should be noted that the number of subjects analyzed was rather small, and there were some interactions which approached significance (probability levels ranged from 0.07 to 0.76). Thus, it will be important to replicate this finding in future work before reaching definitive conclusions. The fact that there were slight in-flight elevations in alpha activity at Fz, Cz, and O1 can probably be attributed to the fact that in-flight testing was always conducted after the laboratory testing which may have allowed subjects to become more relaxed by the time they were seated in the aircraft. Also, it is remotely possible the elevations could have been a product of vibration artifact from the main rotor blades which produce a fundamental frequency of 10.8 Hz; however, this latter explanation is doubtful since the effect was not observed in every EEG channel.

Third, although the amount of theta was not influenced by whether or not the subjects' eyes were opened or closed, there were increases in theta activity from the laboratory to the helicopter environment similar to what was observed in the alpha band. Perhaps this effect also was attributable to subjects becoming more relaxed as the testing day progressed. Regardless of these main effects however, it is noteworthy that once again there were no significant interactions between the testing environment and condition (none even approached significance), which suggests the amount eyes-open/eyes-closed theta was not differentially affected by whether the subjects were evaluated in the helicopter or on the ground.

Fourth, a number of changes in the beta band were found across the two testing environments and eyes-open/eyes-closed conditions. Overall, there was more beta detected from subjects

in the helicopter environment than in the laboratory (significant at Cz and O1), and there was more beta under eyes-closed than eyes-open (at every electrode). An explanation for the main effect attributable to eye closure is not readily apparent at the present, but the main effect of environment (aircraft vs. laboratory) at O1 may have been due to increased neck muscle artifact in the helicopter. This high frequency contamination is apparent in the O1 and O2 EEG depicted earlier in a few of the traces.

Conclusions

This investigation indicated that it is feasible to collect valid in-flight EEG data from helicopter pilots. Furthermore, it is feasible to transmit these data in real time to a ground monitoring station where they can be inspected while the flight is progressing. Such findings lend credibility to the idea that it is possible to continuously evaluate a pilot's functional status during operational flights.

It should be noted, however, that the in-flight collection of laboratory quality EEG epochs for spectral analysis presently necessitates that the data collection periods used in flight be doubled or tripled from the durations normally used in the laboratory. This should permit sufficient flexibility to avoid the increased artifact attributable to subject movements and radio transmissions frequently observed in the aircraft. Also, when preparing for the collection of data in helicopters, both the amplification equipment and the radios must be capable of surviving high temperatures (i.e., greater than 100 degree Fahrenheit) and significant vibration.

Future studies will evaluate the feasibility of monitoring pilots while they are actually engaged in flight-related tasks (as opposed to performing a routine eyes-open/eyes-closed EEG). Also, the feasibility of collecting and analyzing in-flight cortical evoked responses will be assessed.

References

Adey, W. R., Kado, B. S., and Walter, D. O. 1976. Computer analysis of EEG data from Gemini flight GT-7. Aerospace medicine. 38(4):345-359.

AGARD. 1989. Aerospace Medical Panel Working Group 12 and AGARD Lecture Series 163: Human performance assessment methods. AGARDograph No. 308 and AGARDograph No. 308 (Addendum).

Belyavin, A., and Wright, N. A. 1987. Changes in electrical activity of the brain with vigilance. Electroencephalography and clinical Neurophysiology. 66: 137-144.

Blanc, C., LaFontaine, E., and Medvedeff, M. 1966. Radiotelemetric recordings of the electroencephalograms of civil aviation pilots during flight. Aerospace medicine. October:1060-1065.

Caldwell, J. A., Carter, D. J., Stephens, R. L., Stone, L. W., Delrie, D. M., Pearson, J. Y., and Simmons, R. R. 1991. Effects of the chemical defense antidote atropine sulfate on helicopter pilot performance: An in-flight study. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 91-17.

Caldwell, J. A., Stephens, R. L., and Carter, D. J. 1992. The effects of 2 mg and 4 mg atropine sulfate on the performance of U.S. Army helicopter pilots. Aviation, Space, and Environmental Medicine, 63(10):857-864.

Comperatore, C. A., Caldwell, J. A., Stephens, R. L., Mattingly, A., Chiaramonte, J., and Trast, S.T. 1993. The use of electrophysiological and cognitive variables in the assessment of degradation during periods of sustained wakefulness. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 93-5.

Dellinger, J. A., Taylor, H. L., and Richardson, B. C. 1986. Comparison of the effects of atropine sulfate and ethanol on performance. Aviation, space, and environmental medicine. 57:1185-1188.

Fink, M., and Irwin, P. 1979. CNS effects of the antihistamines diphenhydramine and terfenadine (RMI 9918). Pharmacopsychiatry, 12:35-44.

Goldstein, L., Murphree, H. B., and Pfeiffer, C. C. 1968. Comparative study of EEG effects of antihistamines in normal volunteers. The Journal of clinical pharmacology, (January-February):42-53.

Greenfield, N. S., and Sternbach, R. A. (Eds.). 1972. Electrical activity of the brain. Handbook of psychophysiology. New York: Holt, Rinehart, and Winston, Inc.

Howitt, J. S., Hay, A. E., Shergold, G. R., and Ferres, H. M. 1978. Workload and fatigue in-flight EEG changes. Aviation, space, and environmental medicine. 49:1197-1202.

Lees, M. A., and Ellingstad, V. S. 1990. Assessing human performance during the operation of dynamic vehicles: A literature review and examination of methods. Fort Rucker, AL: United States Army Aeromedical Research Laboratory. USAARL Report No. CR-90-2.

Maulsby, R. L. 1966. Electroencephalogram during orbital flight. Aerospace medicine. October:1022-1026.

Nebylitsyn, V. D., and Mozgovoy, V. D. 1973. Electrophysiological correlates of mental activity. Translated from Zhurnal vysshey nervnoy dehatel'nosti. 22:899-906.

Petrek, J. 1982. Reflection of changes in level of excitability of the central nervous system under stress in some physiological functions of an organism. Acta Universitatis Palackianae Olomucensis 103:29-41.

Pickworth, W. B., Herning, R. I., Koeppl, B., and Henningfield, J. E. 1990. Dose-dependent atropine-induced changes in spontaneous electroencephalogram in human volunteers. Military medicine. 155(4):166-170.

Pigeau, R. A., Heselegrave, R. J., and Angus, R. G. 1987. Psychophysiological measures of drowsiness as estimators of mental fatigue and performance degradation during sleep deprivation in Electric and magnetic activity of the central nervous system: Research and clinical applications in aerospace medicine, AGARD Symposium, Trondheim, Norway.

Sem-Jacobsen, C. W. 1961. Electroencephalographic study of pilot stresses in flight. Monitoring agency document No.AFOSR1727, Technical Report of Contract No. AF 61 (052)-197.

Sem-Jacobsen, C. W., and Sem-Jacobsen, I. E. 1963. Selection and evaluation of pilots for high performance aircraft and spacecraft by in-flight EEG study of stress tolerance. Aerospace medicine. 34:605-609.

Sem-Jacobsen, C. W., Nilseng, O., Patten, C., and Eriksen, O. 1959. Electroencephalographic recording in simulated combat flight in a jet fighter plane. Electroencephalography and clinical neurophysiology. 11:154-155.

Simmons, R. R., Caldwell, J. A., Stephens, R. L., Stone, L. W., Carter, D. J., Behar, I., Mitchell, G. W., Knox, F. S., Jones, H. D., and Taylor, P. L. 1989. Effects of the chemical defense antidote atropine sulfate on helicopter pilot performance: A simulator study. U.S. Army Aeromedical Research Laboratory Technical Report, No. 89-17.

Sterman, M. B., Schummer, G. J., Dushenko, T. W., and Smith, J. C. 1987. Electroencephalographic correlates of pilot performance: Simulation and in-flight studies. In: Electrical and magnetic activity of the central nervous system: Research and clinical applications in aerospace medicine. Neuilly Sur Seine, France: NATO. AGARD CP No. 432:31-1/31-16.

Vollmer, R., Matejced, M., Greenwood, C., Grisold, W., and Jelinger, K. 1983. Correlation between EEG changes indicative of sedation and subjective responses. Neuropsychobiology. 10:249-253.

Wilson, G. F., Purvis, B., Skelly, J., Fullenkamp, P., and Davis, I. 1987. Physiological data used to measure pilot workload in actual flight and simulator conditions. Proceedings of the Human Factors society, 31st annual meeting. 779-783.

Appendix A.

Examples of EEG data collected from each subject.

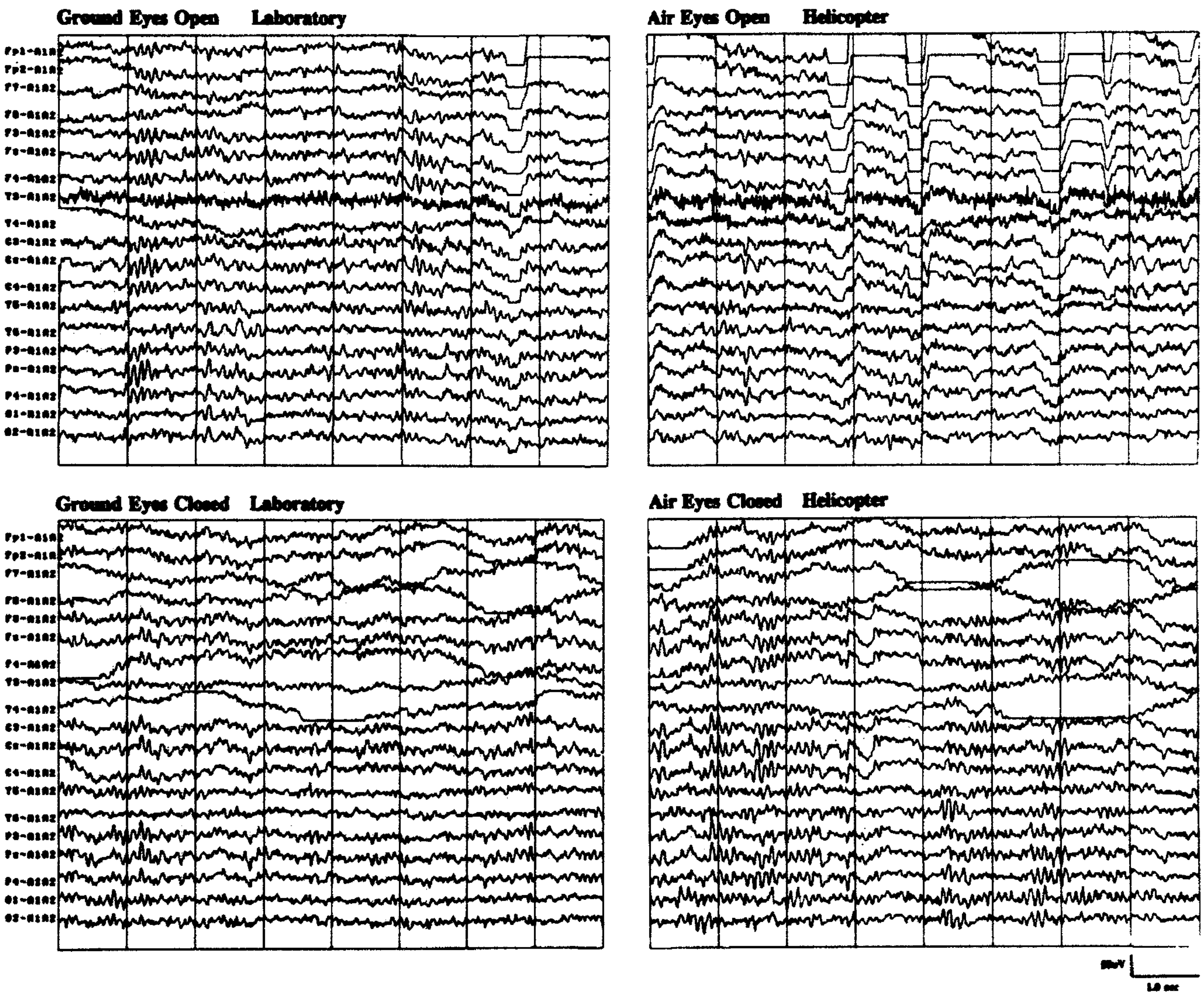

Figure A-1. An 8-second page of EEG data collected from subject 1 collected under eyes-open and eyes-closed conditions in the helicopter and in the laboratory.

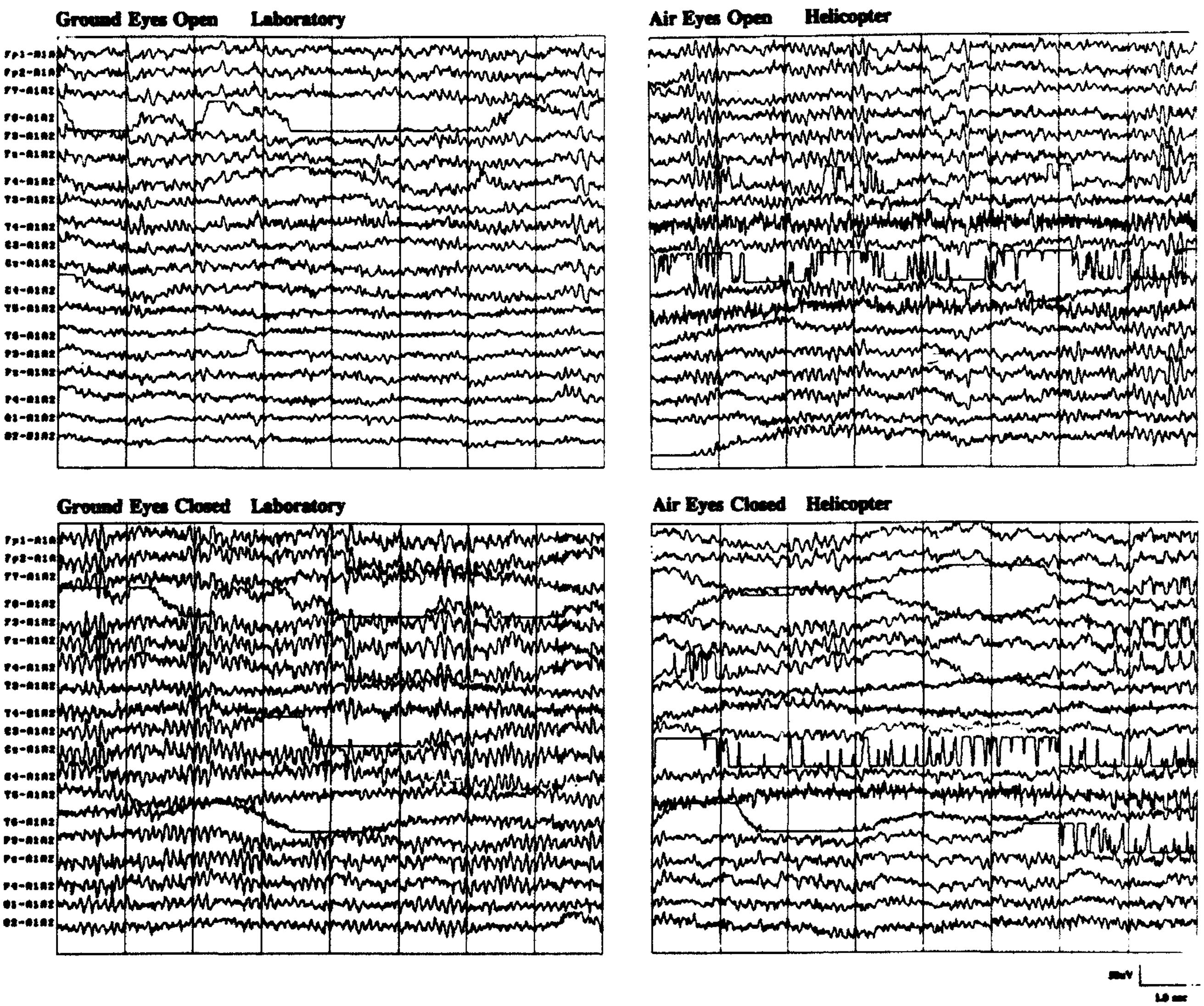

Figure A-2. An 8-second page of EEG data collected from subject 2 collected under eyes-open and eyes-closed conditions in the helicopter and in the laboratory.

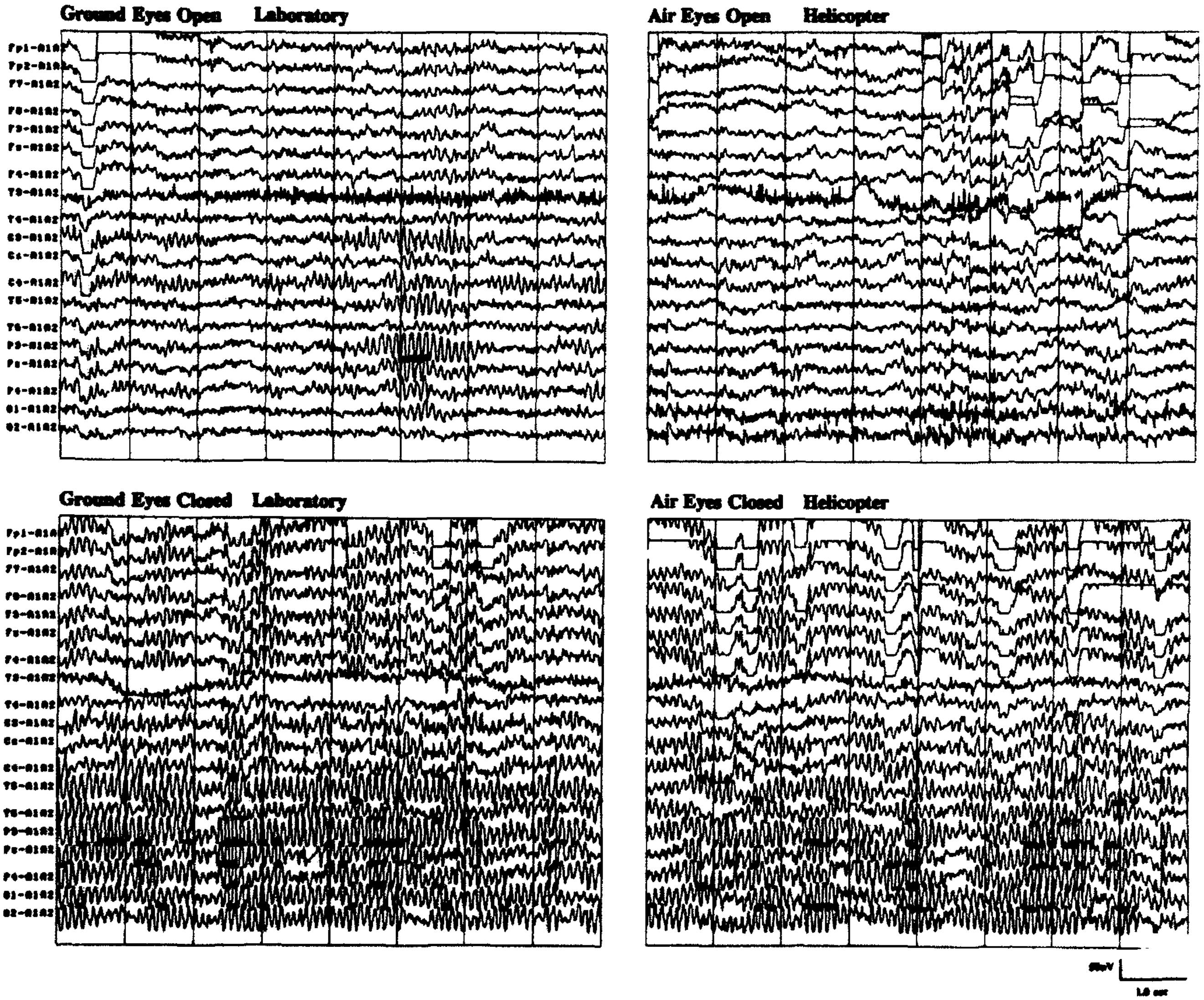

Figure A-3. An 8-second page of EEG data collected from subject 3 collected under eyes-open and eyes-closed conditions in the helicopter and in the laboratory.

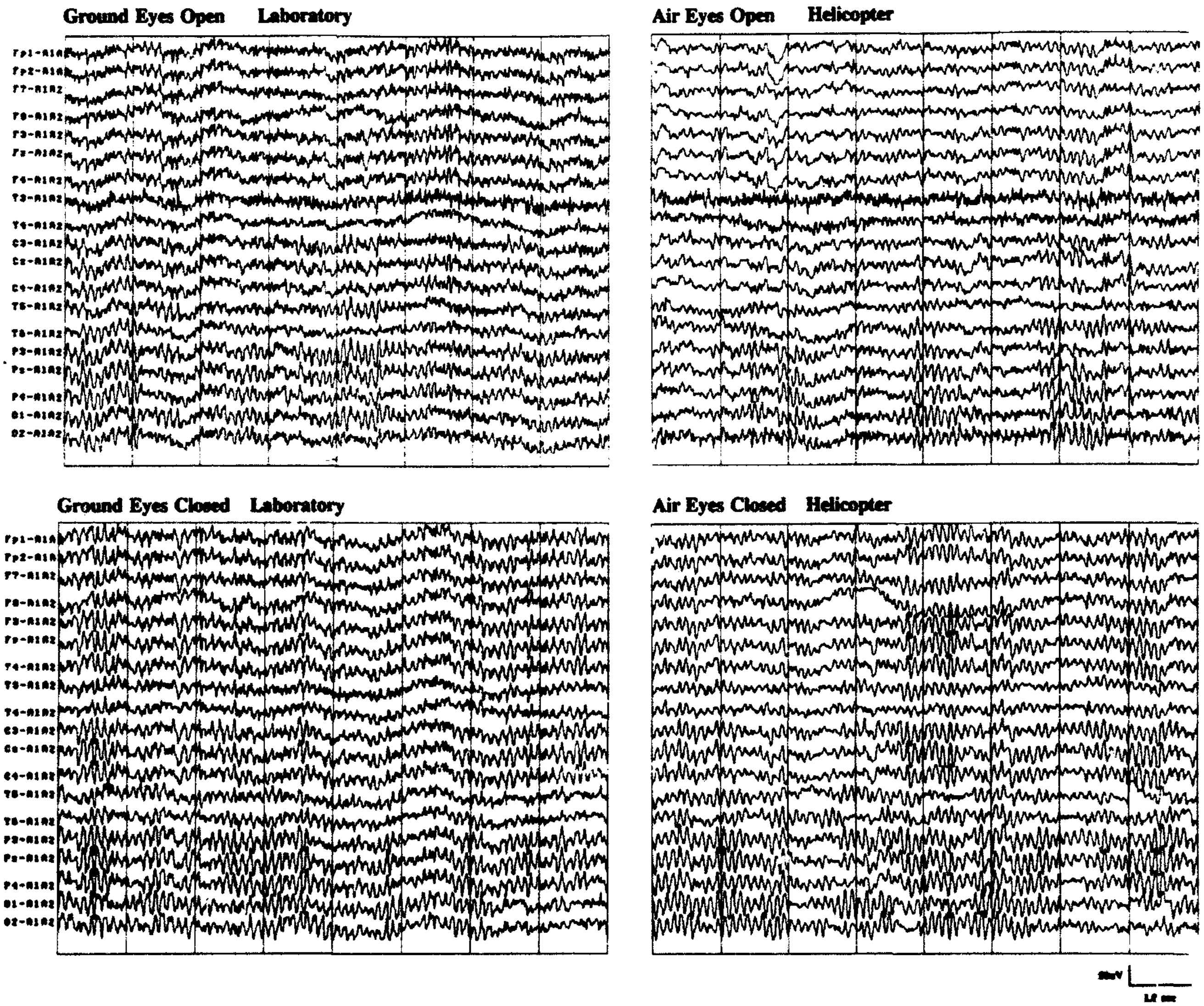

Figure A-4. An 8-second page of EEG data collected from subject 4 collected under eyes-open and eyes-closed conditions in the helicopter and in the laboratory.

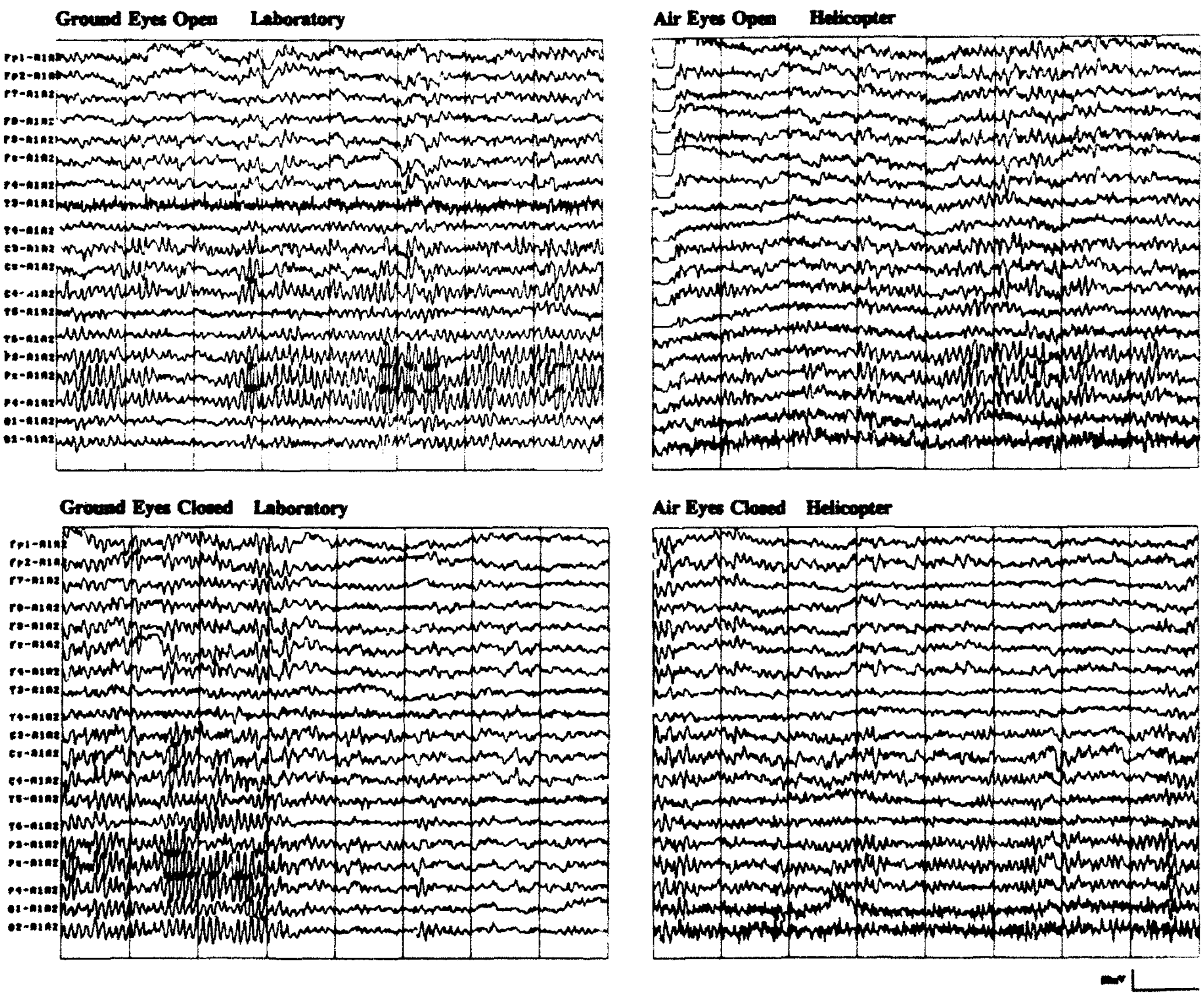

Figure A-5. An 8-second page of EEG data collected from subject 5 collected under eyes-open and eyes-closed conditions in the helicopter and in the laboratory.

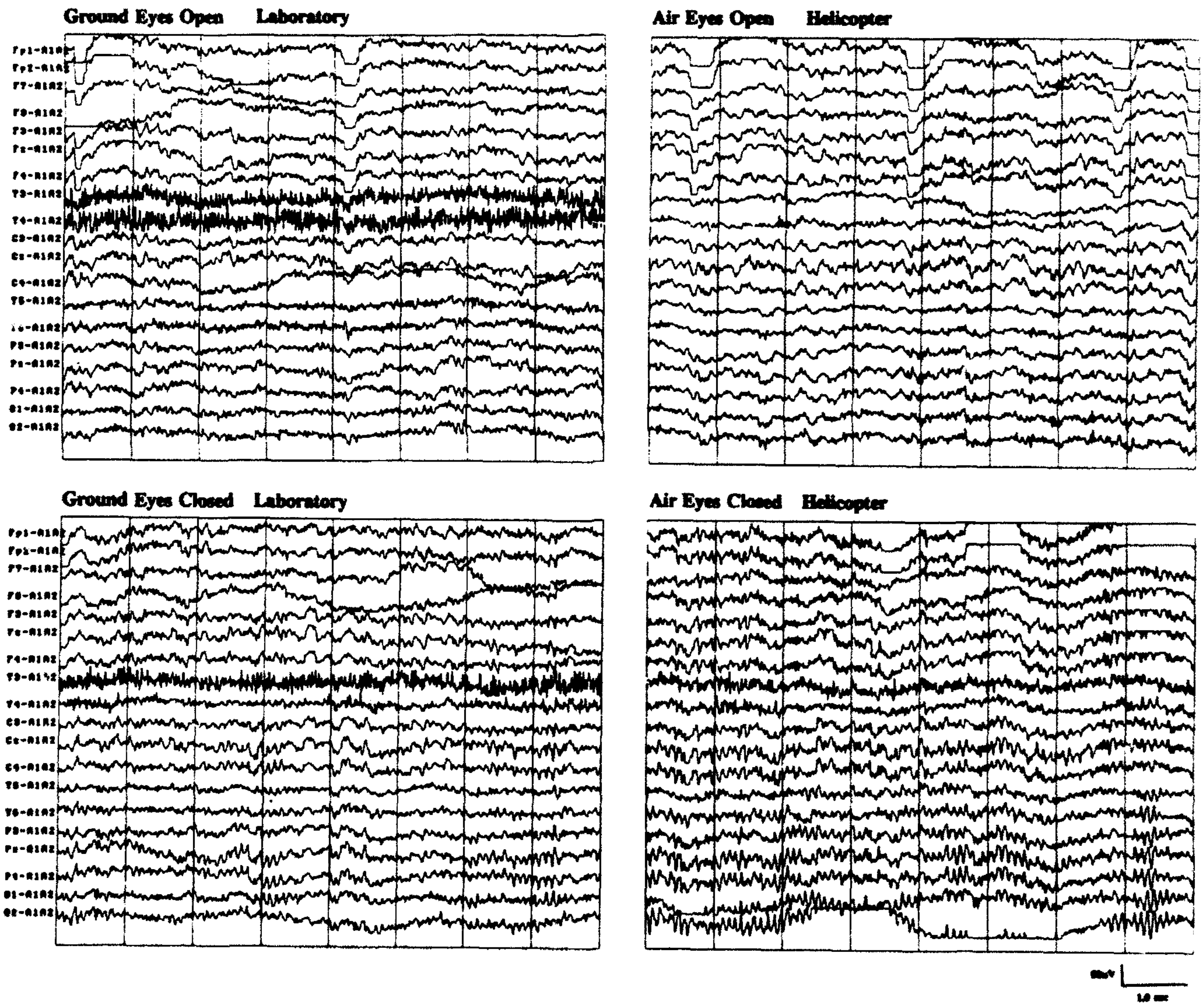

Figure A-6. An 8-second page of EEG data collected from subject 6 collected under eyes-open and eyes-closed conditions in the helicopter and in the laboratory.

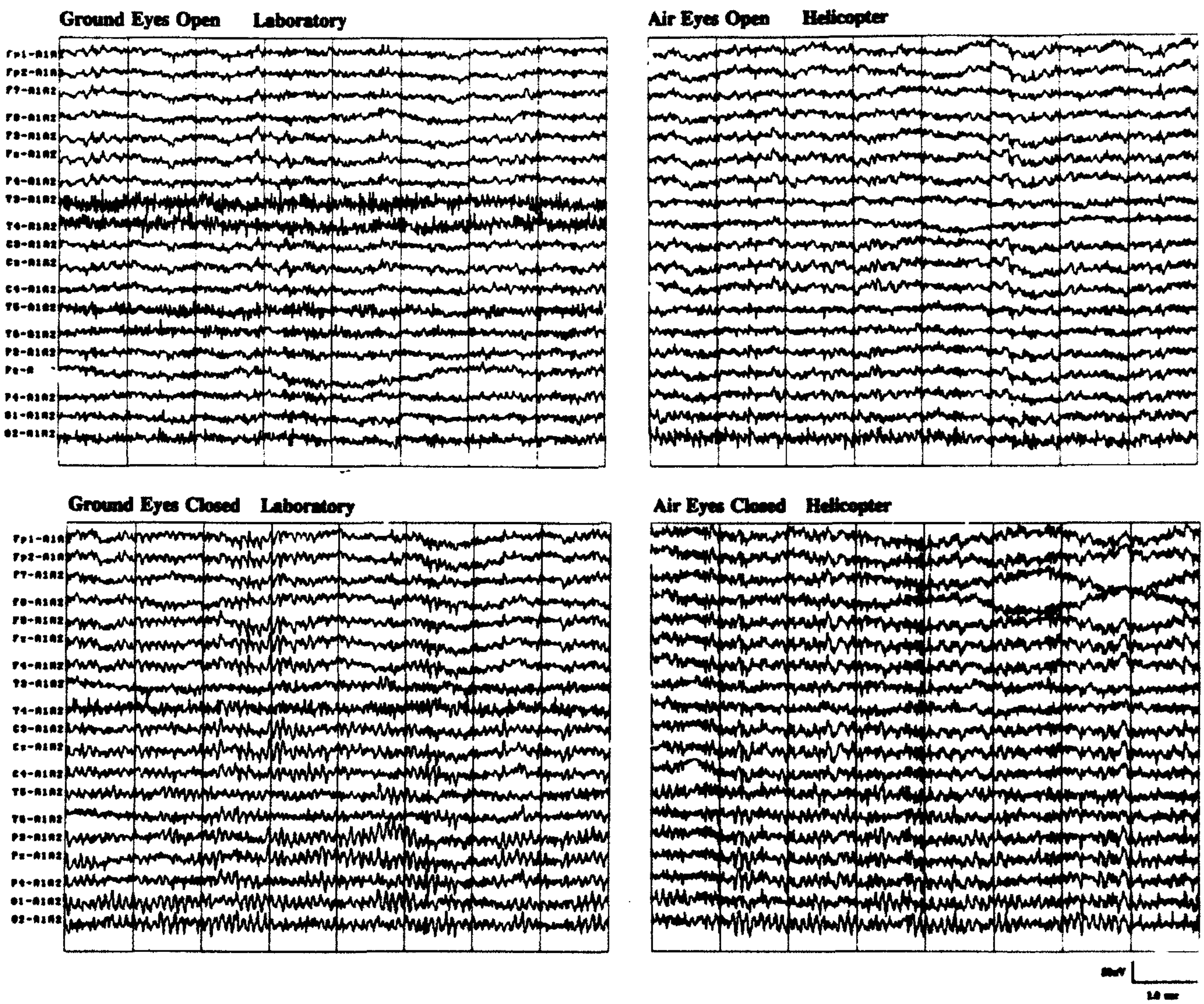

Figure A-7. An 8-second page of EEG data collected from subject 7 collected under eyes-open and eyes-closed conditions in the helicopter and in the laboratory.

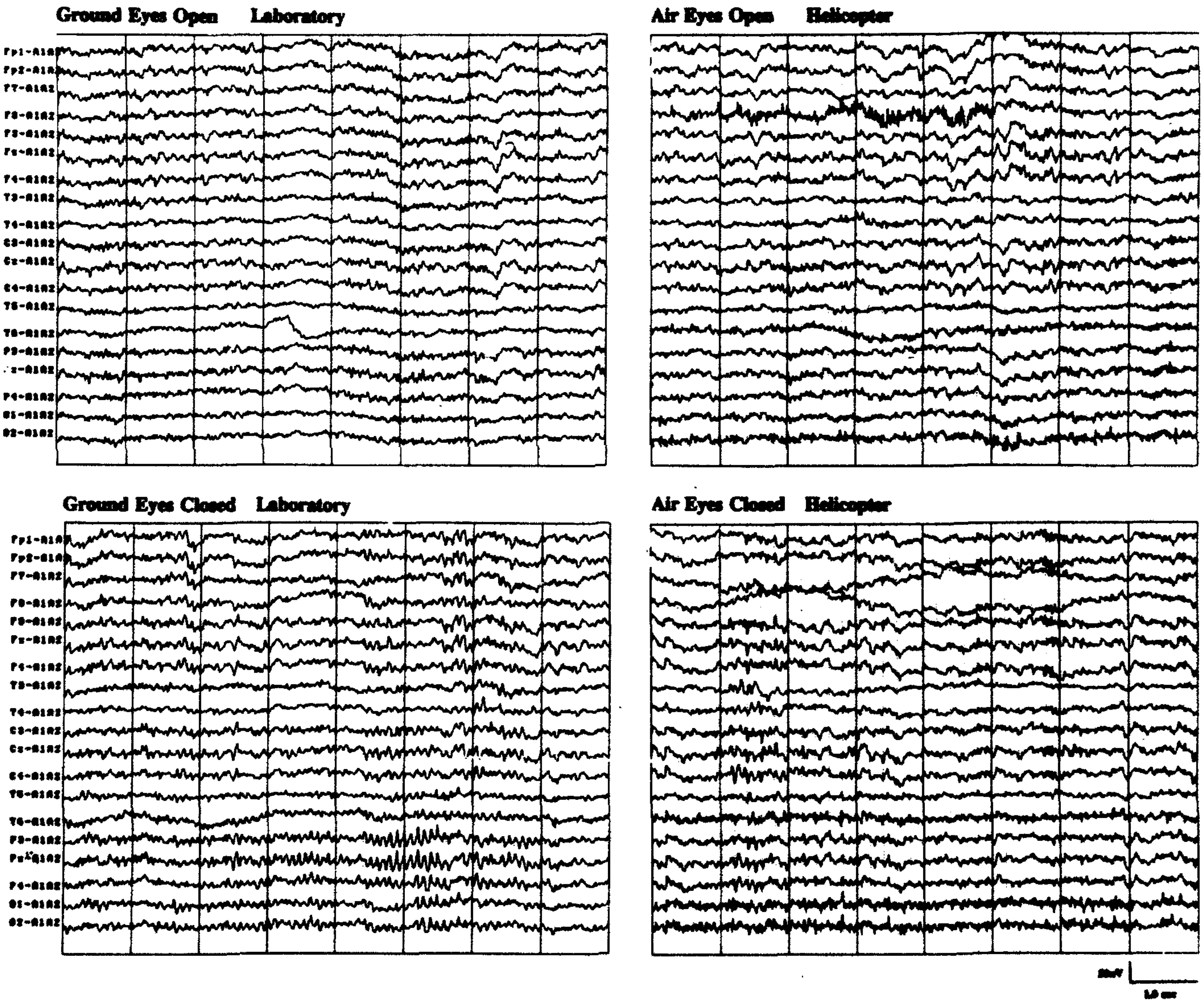

Figure A-8. An 8-second page of EEG data collected from subject 8 collected under eyes-open and eyes-closed conditions in the helicopter and in the laboratory.

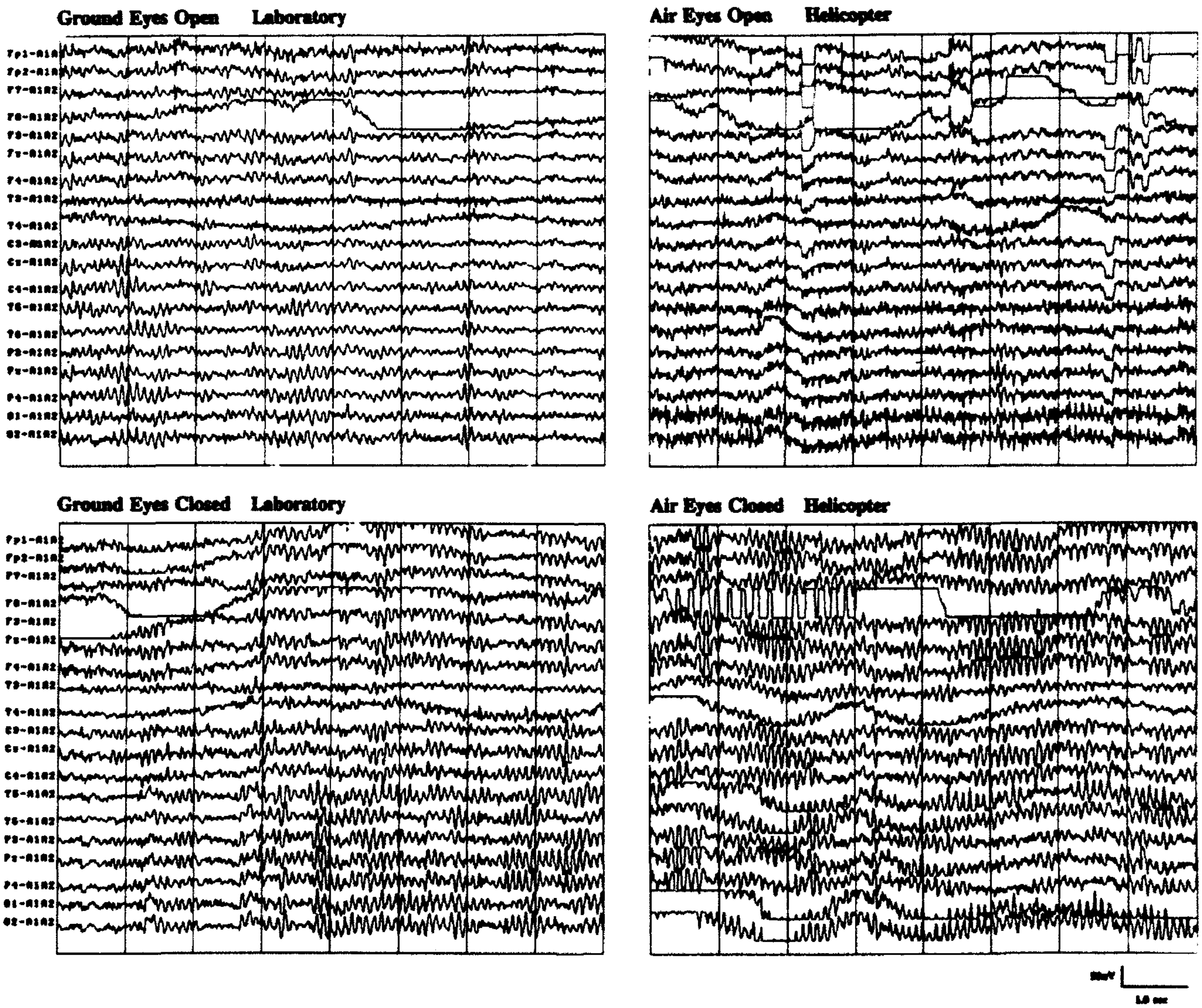

Figure A-9. An 8-second page of EEG data collected from subject 9 collected under eyes-open and eyes-closed conditions in the helicopter and in the laboratory.

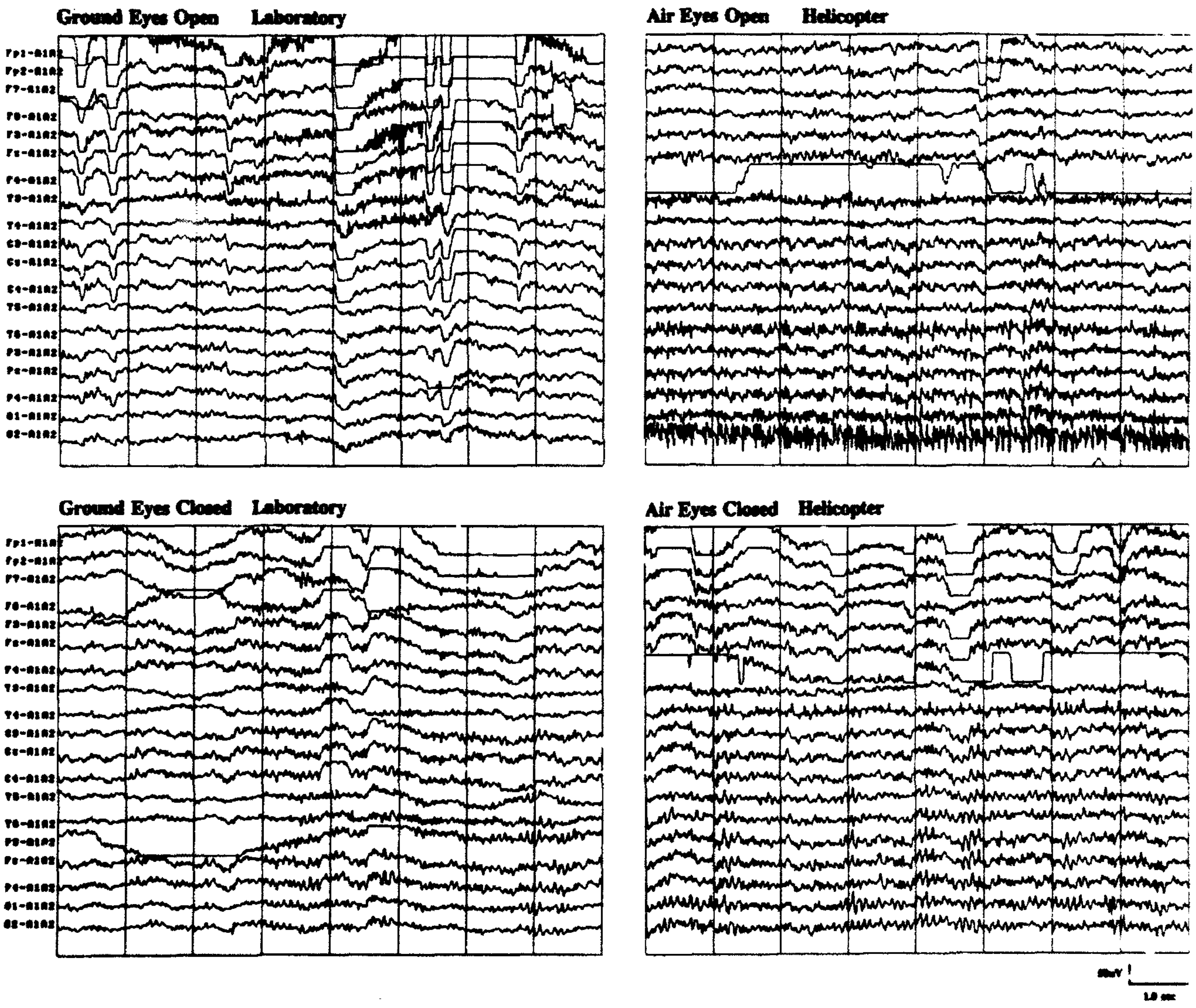

Figure A-10. An 8-second page of EEG data collected from subject 10 collected under eyes-open and eyes-closed conditions in the helicopter and in the laboratory.

Appendix B.

Relatively artifact-free epochs for spectral analyses.

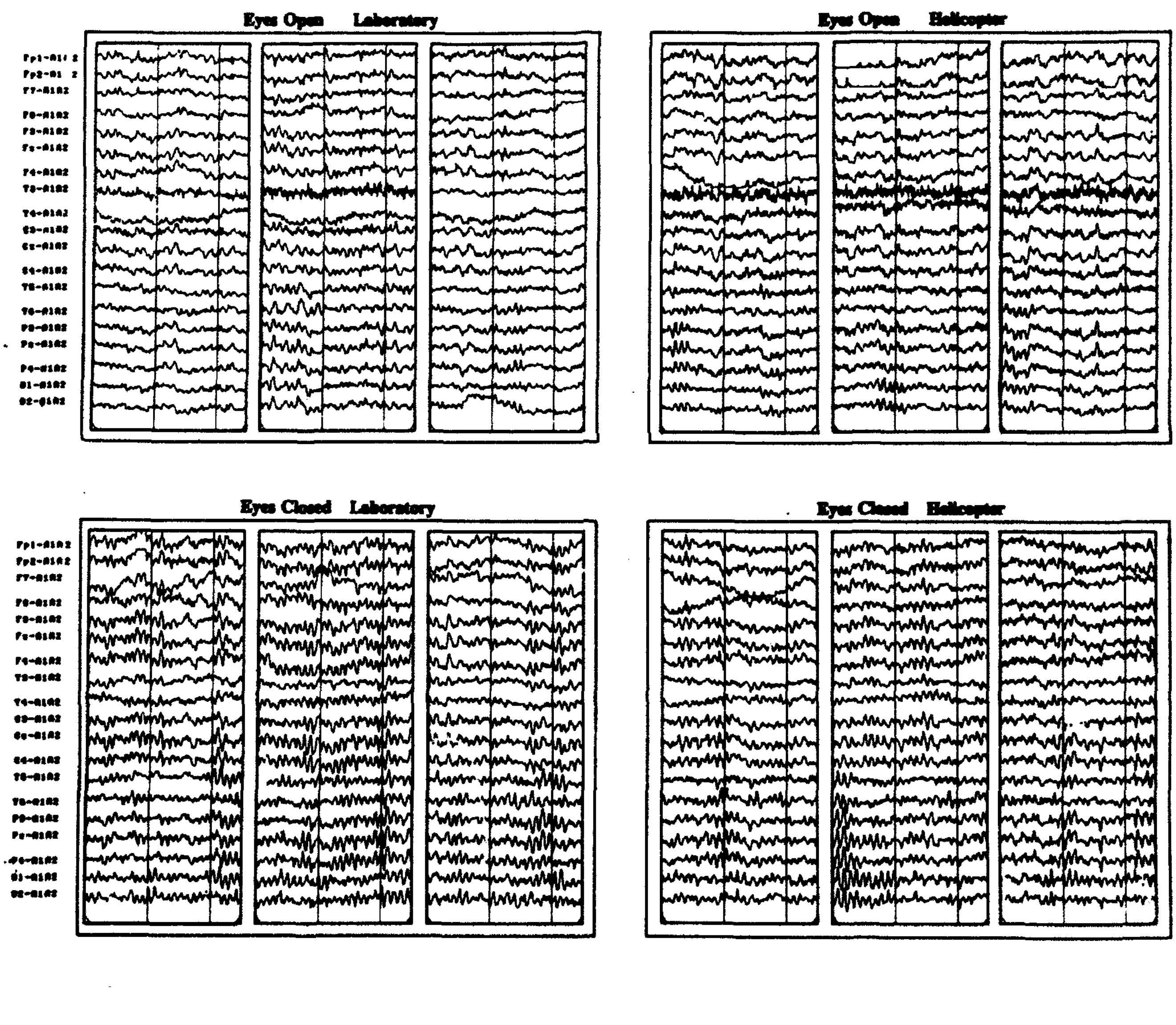

Figure B-1. The three artifact-free EEG epochs on which spectral analyses were conducted for subject 1 under each condition in the helicopter and in the laboratory.

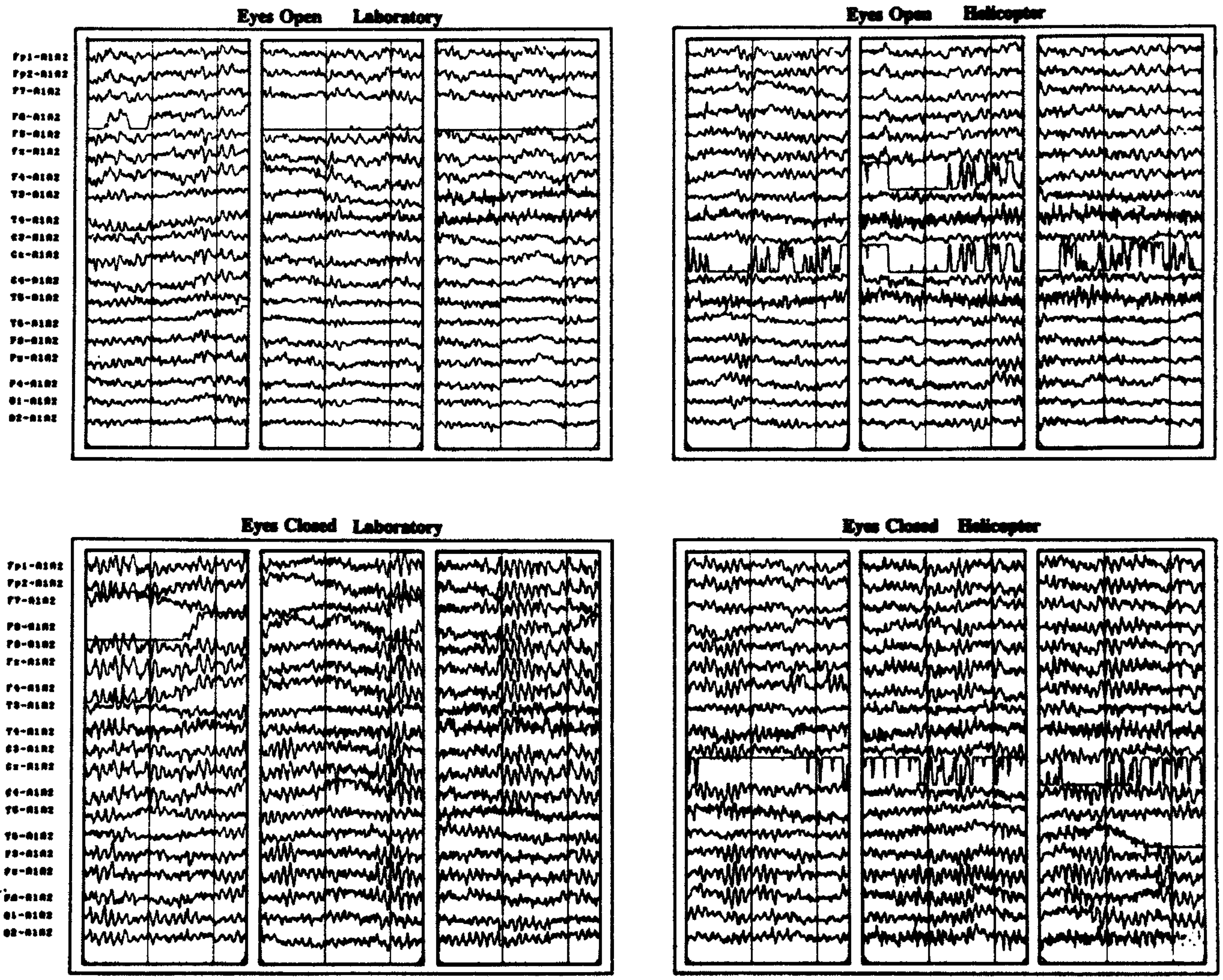

Figure B-2. The three artifact-free EEG epochs on which spectral analyses were conducted for subject 2 under each condition in the helicopter and in the laboratory (Cz data was set to missing for the in-flight data).

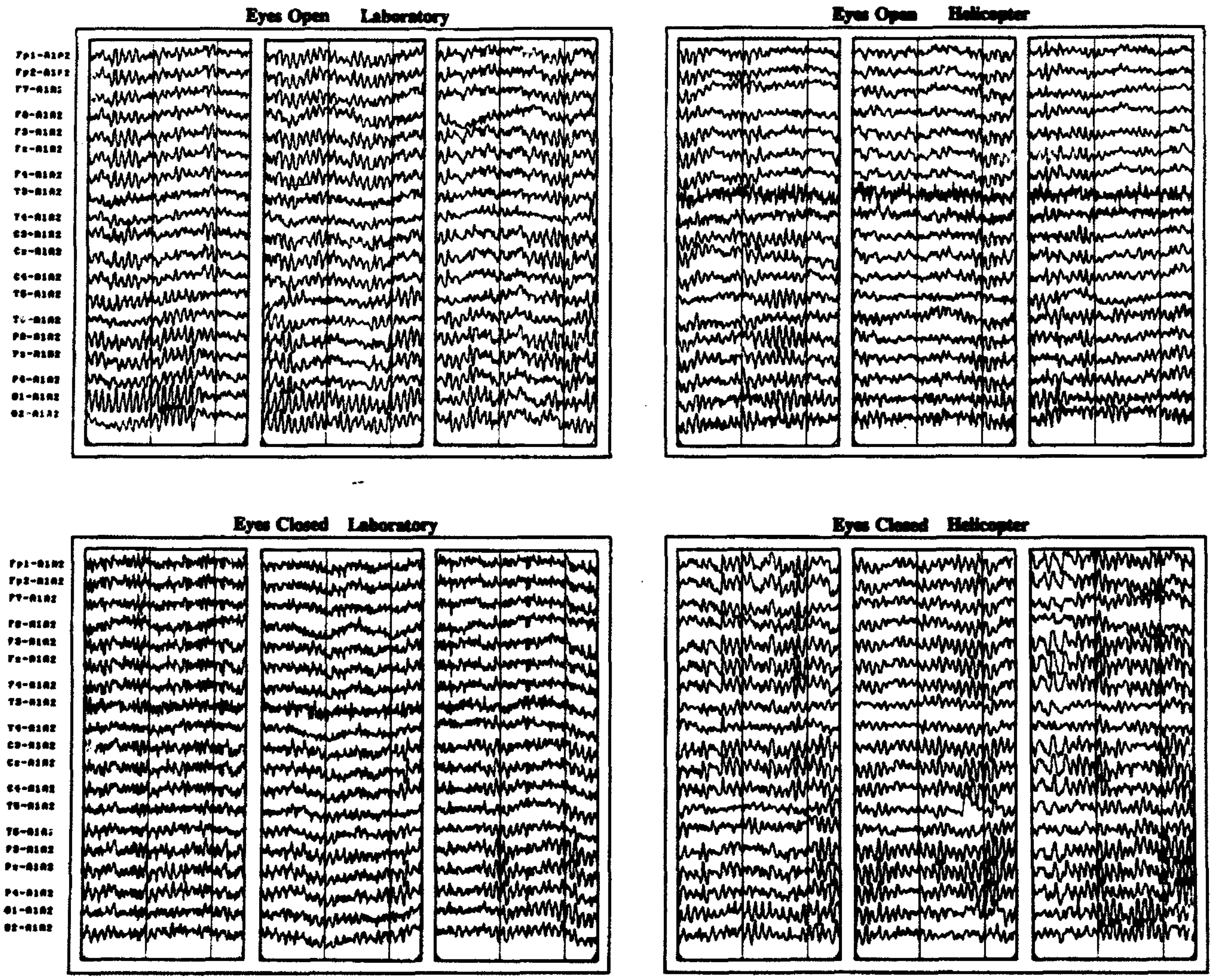

Figure B-3. The three artifact-free EEG epochs on which spectral analyses were conducted for subject 4 under each condition in the helicopter and in the laboratory.

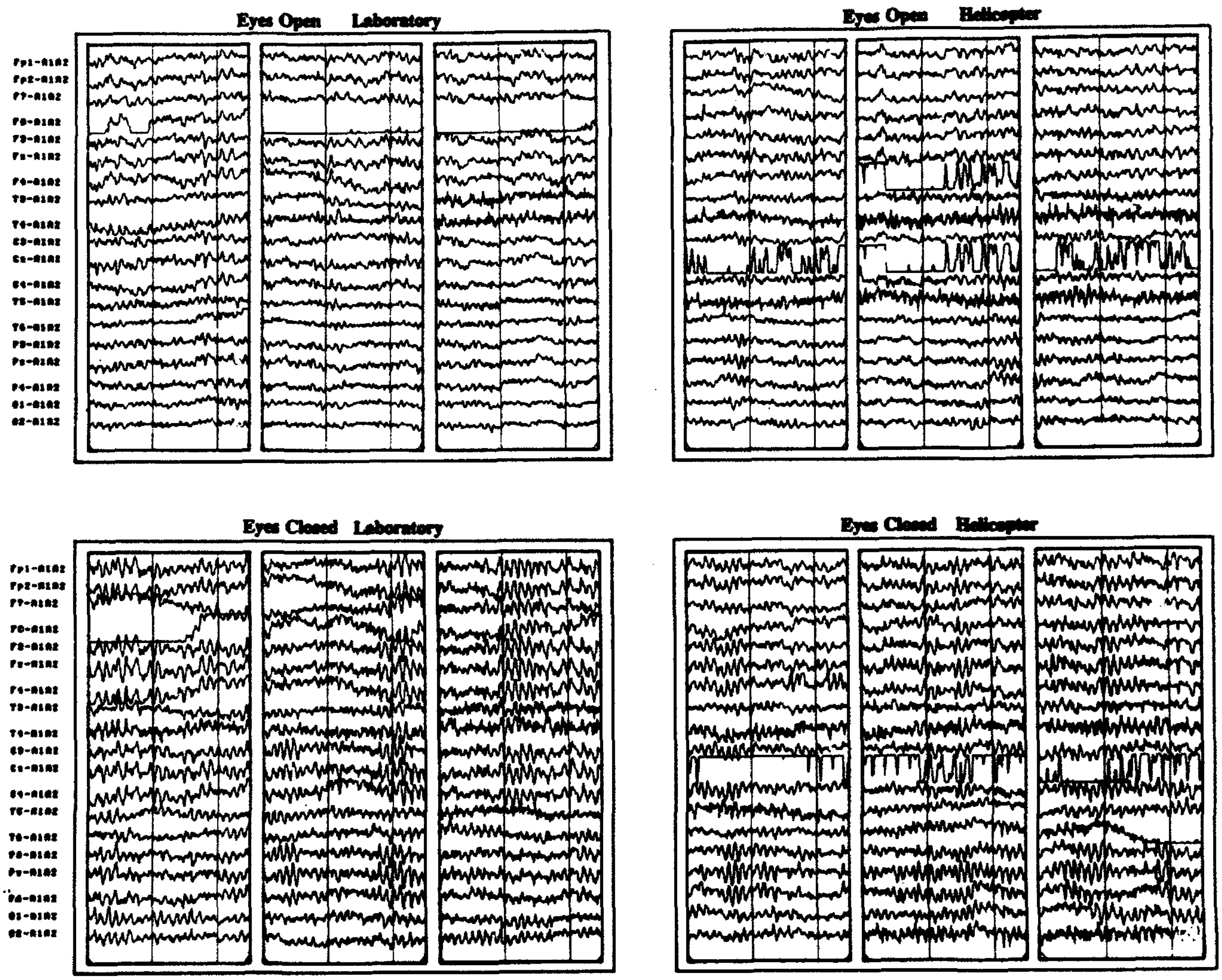

Figure B-2. The three artifact-free EEG epochs on which spectral analyses were conducted for subject 2 under each condition in the helicopter and in the laboratory (Cz data was set to missing for the in-flight data).

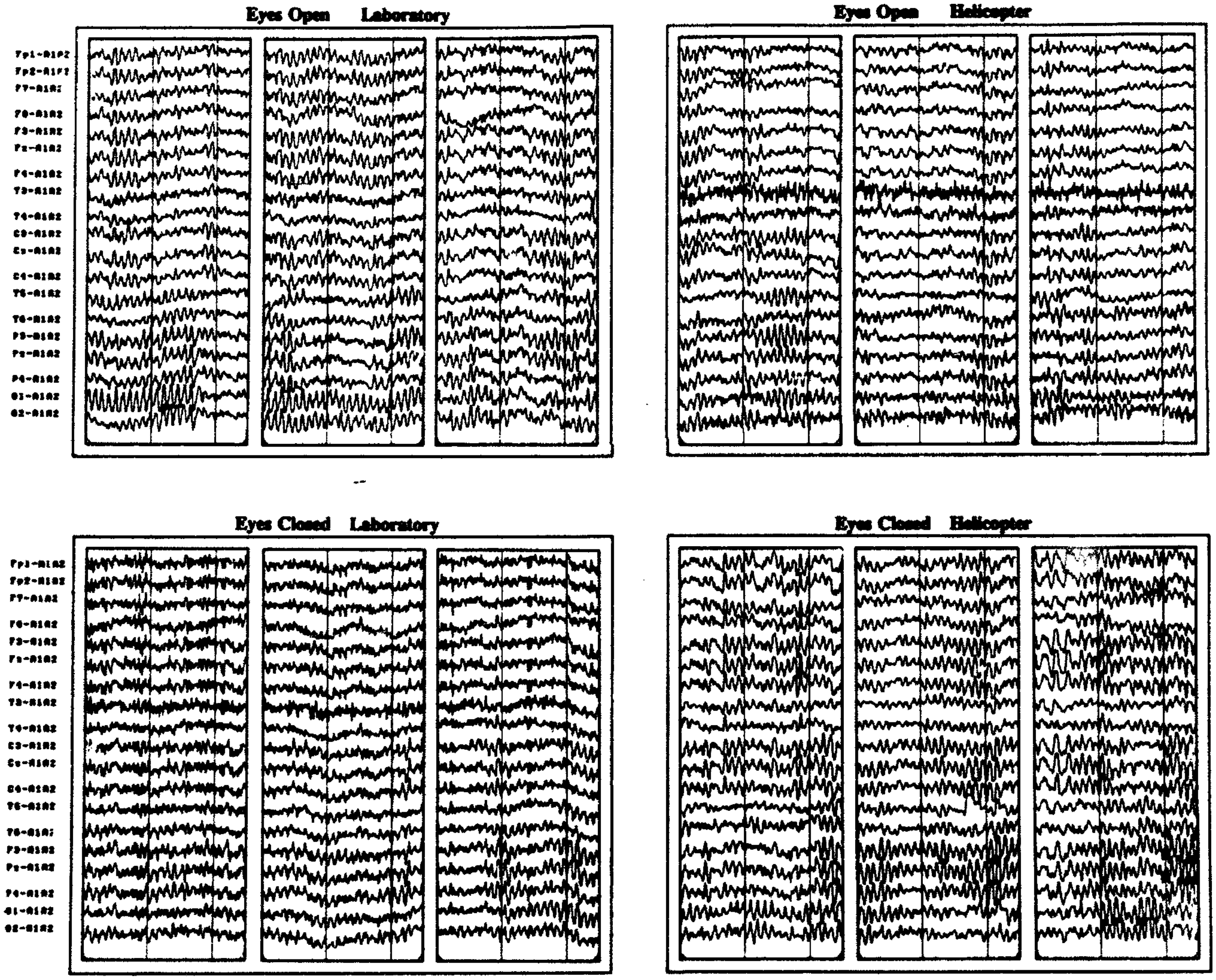

Figure B-3. The three artifact-free EEG epochs on which spectral analyses were conducted for subject 4 under each condition in the helicopter and in the laboratory.

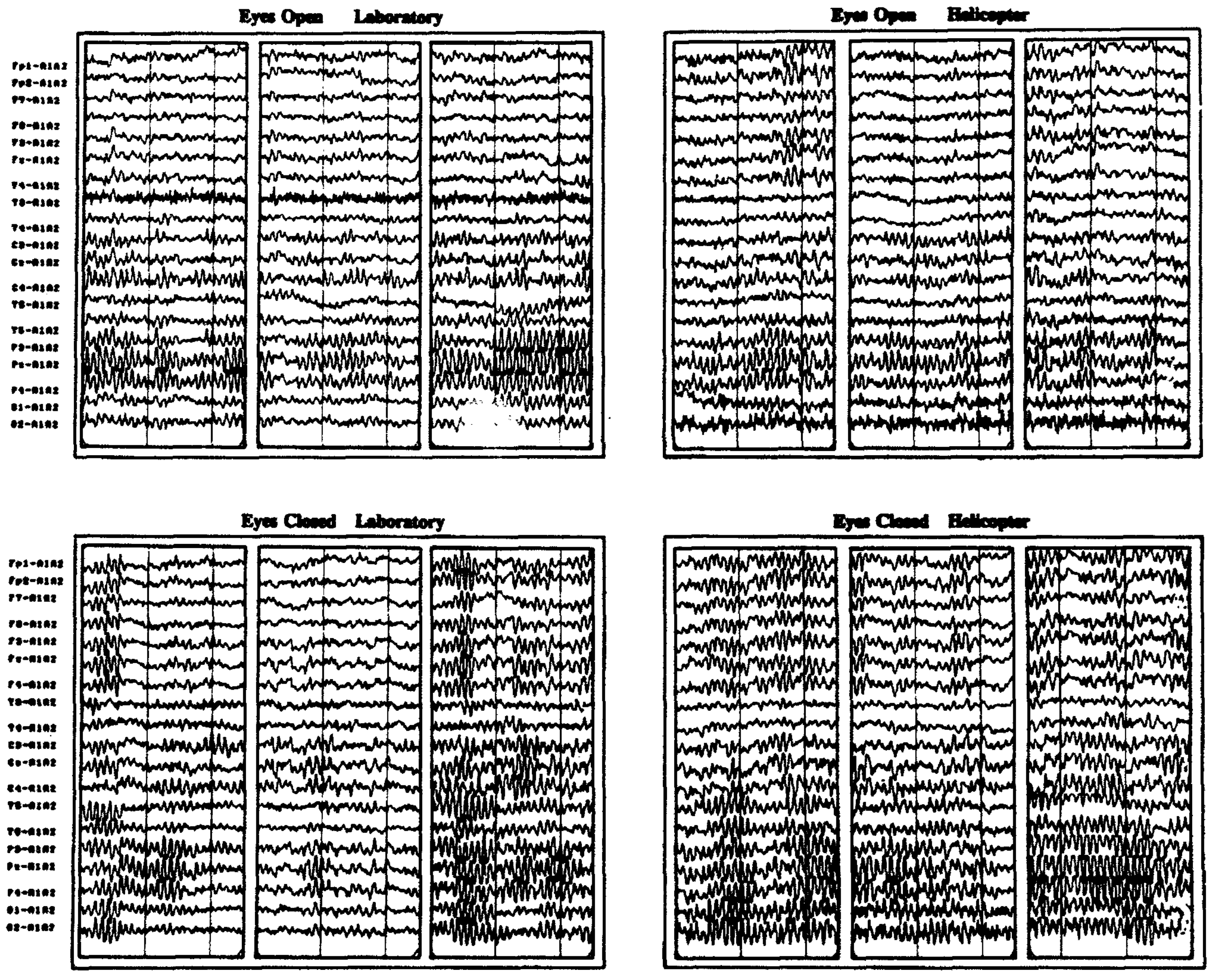

Figure B-4. The three artifact-free EEG epochs on which spectral analyses were conducted for subject 5 under each condition in the helicopter and in the laboratory.

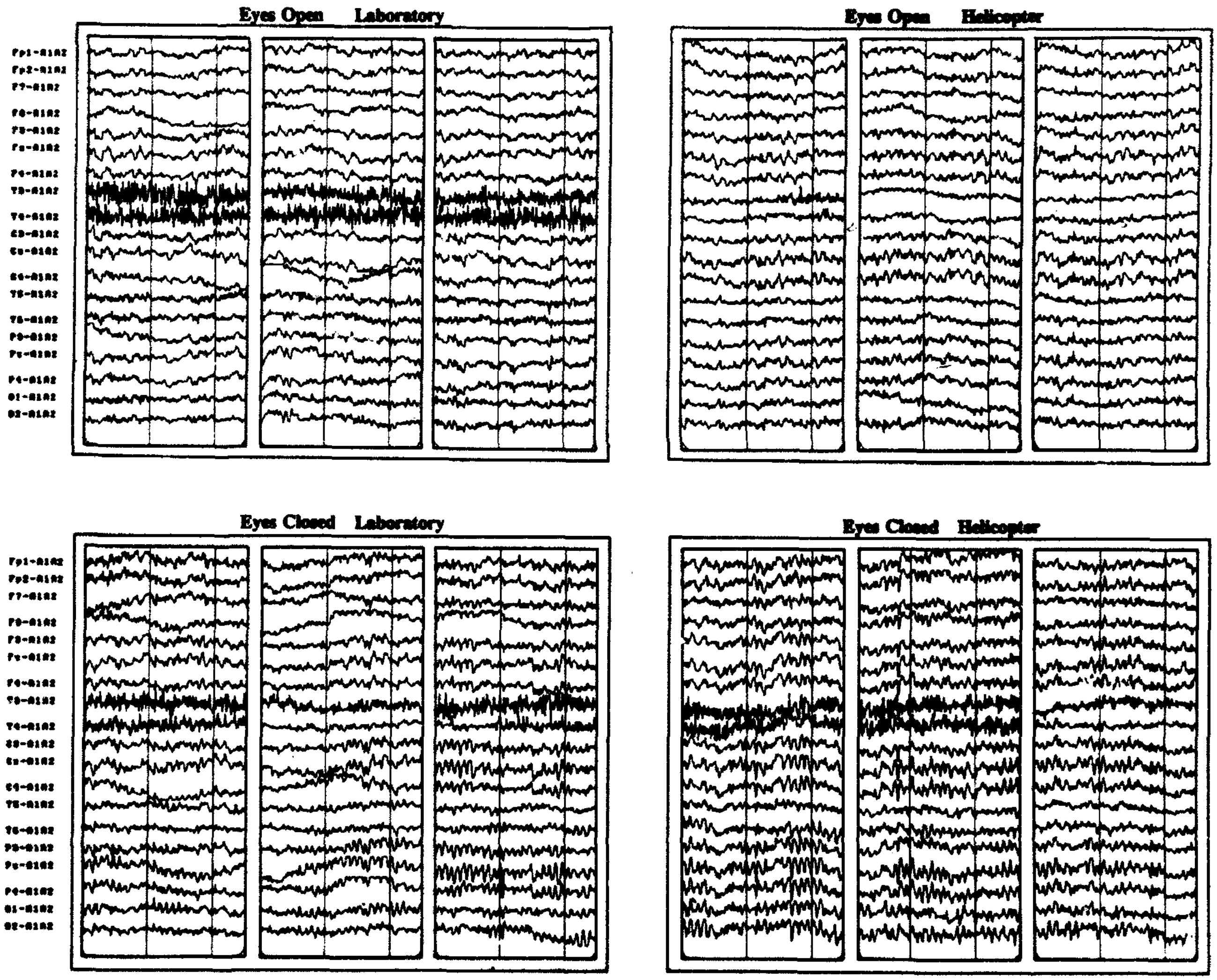

Figure B-5. The three artifact-free EEG epochs on which spectral analyses were conducted for subject 6 under each condition in the helicopter and in the laboratory.

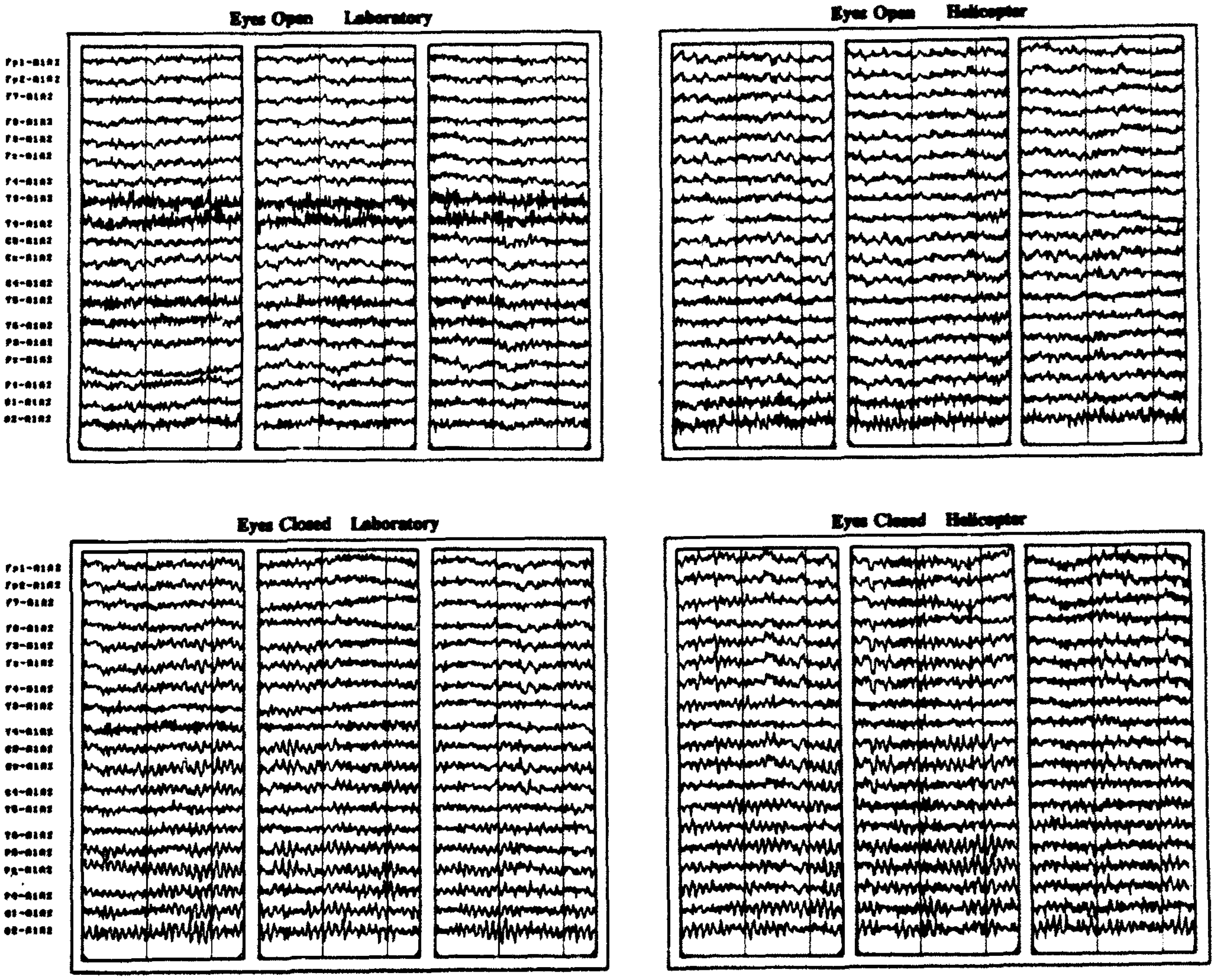

Figure B-6. The three artifact-free EEG epochs on which spectral analyses were conducted for subject 7 under each condition in the helicopter and in the laboratory.

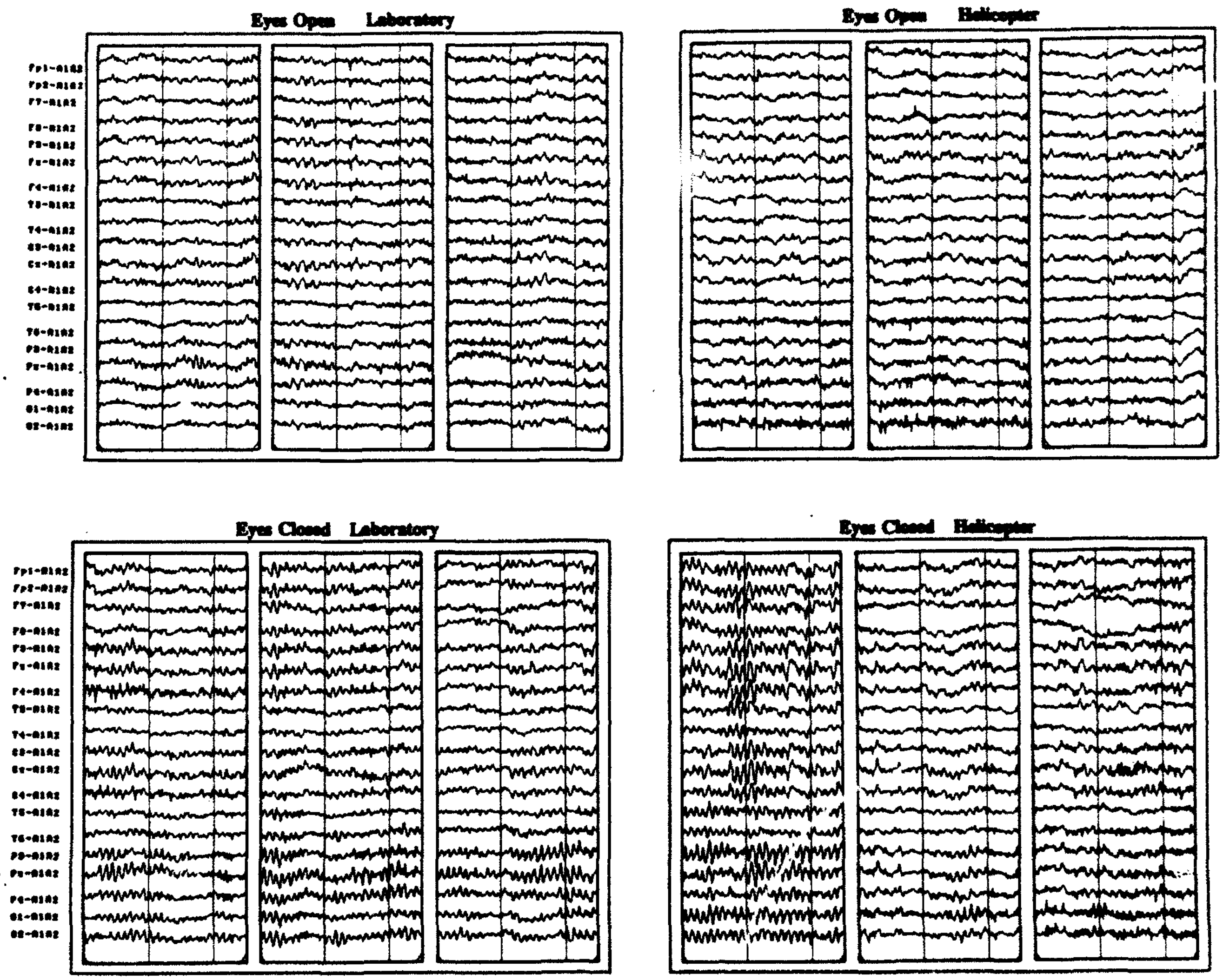

Figure B-7. The three artifact-free EEG epochs on which spectral analyses were conducted for subject 8 under each condition in the helicopter and in the laboratory.

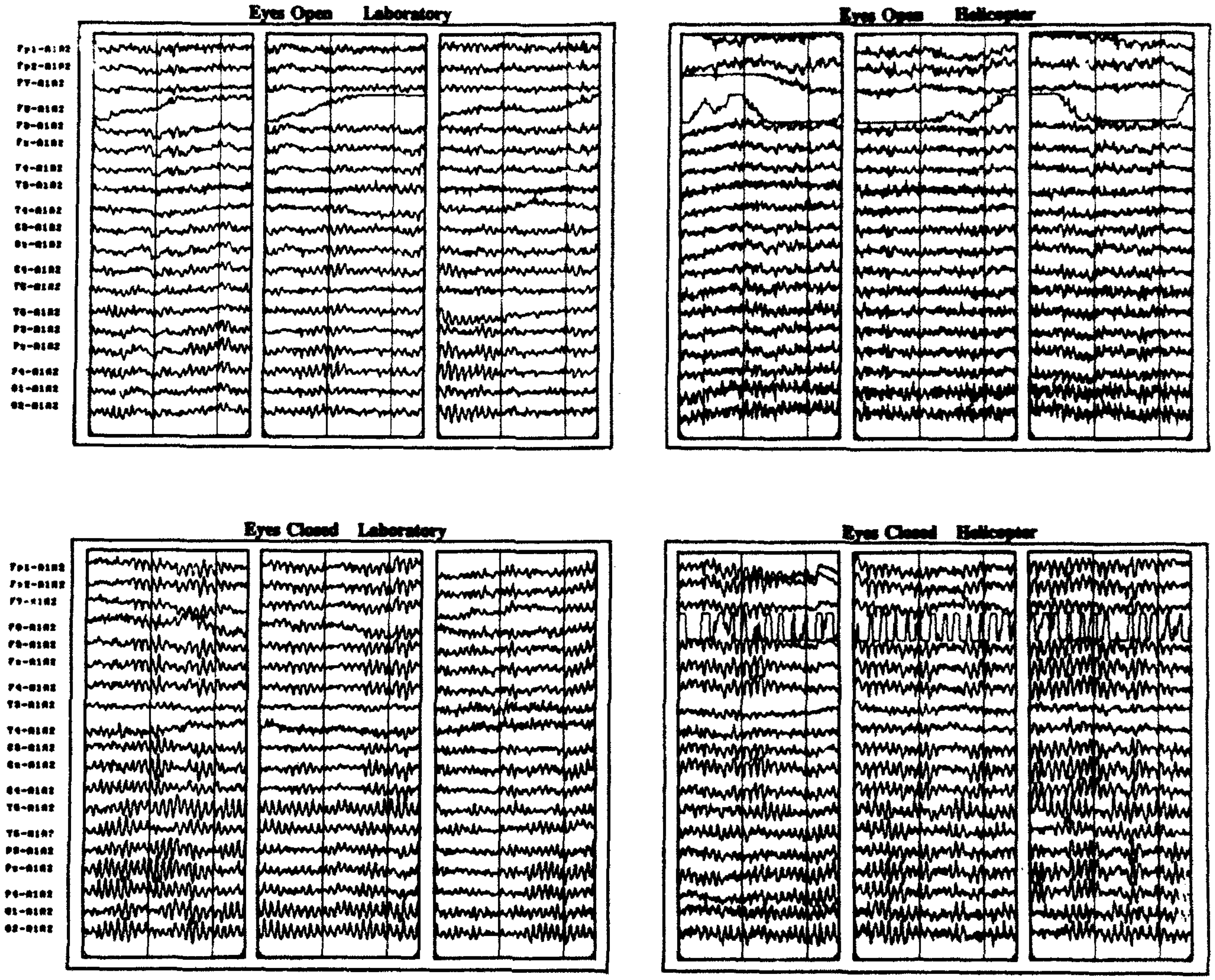

Figure B-8. The three artifact-free EEG epochs on which spectral analyses were conducted for subject 9 under each condition in the helicopter and in the laboratory.

Appendix C.

List of manufacturers.

Cadwell Laboratories, Inc.
1021 Kellogg Street
Kennewick, WA 99336

Anixter Communication Systems
Mark Antenna Division
2180 South Wolf Road
Des Plaines, IL

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7322 Convoy Court
San Diego, CA 92111
(619) 560-8601

K&L Microwave Incorporated
408 Cole Circle
Salisbury, MD 21801
(301) 749-2424

Loral Terracom
9020 Balboa Avenue
San Diego, CA 92123
(714) 278-4100

Tecom Industries
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Chatsworth, CA 91311
(818) 341-1402

Initial distribution

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Washington, DC 20594

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APO New York 09180

Naval Air Development Center
Technical Information Division
Technical Support Detachment
Warminster, PA 18974

Commanding Officer, Naval Medical
Research and Development Command
National Naval Medical Center
Bethesda, MD 20814-5044

Deputy Director, Defense Research
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Washington, DC 20301-3080

Commander, U.S. Army Research
Institute of Environmental Medicine
Natick, MA 01760

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Groton, CT 06349-5900

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Naval Air Development Center
Warminster, PA 18974

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Warminster, PA 18974

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Armstrong Laboratory
Wright-Patterson
Air Force Base, OH 45433-6573

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Army Audiology and Speech Center
Walter Reed Army Medical Center
Washington, DC 20307-5001

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Fort Monmouth, NJ 07703-5305

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FAA Technical Center
Atlantic City, NJ 08405

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Naval Air Systems Command
Technical Air Library 950D
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Department of the Navy
Washington, DC 20361

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Aberdeen Proving Ground, MD 21005

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Institute of Chemical Defense
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Aberdeen Proving Ground,
MD 21010-5425

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USAMRDALC
ATTN: SGRD-RMS
Fort Detrick, Frederick, MD 21702-5012

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HQ DA (DASG-PSP-O)
5109 Leesburg Pike
Falls Church, VA 22041-3258

Harry Diamond Laboratories
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2800 Powder Mill Road
Adelphi, MD 20783-1197

U.S. Army Materiel Systems
Analysis Agency
ATTN: AMXSY-PA (Reports Processing)
Aberdeen Proving Ground
MD 21005-5071

U.S. Army Ordnance Center
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Aberdeen Proving Ground, MD 21005

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Aberdeen Proving Ground, MD 21010

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Aberdeen Proving Ground, MD
21010-5423

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Office of Naval Research
600 North Quincy Street
Arlington, VA 22217

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5001 Eisenhower Avenue
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Logistics School ATTN: ATSQ-TDN
Fort Eustis, VA 23604

Headquarters (ATMD)
U.S. Army Training
and Doctrine Command
ATTN: ATBO-M
Fort Monroe, VA 23651

IAF Liaison Officer for Safety
USAF Safety Agency/SEFF
9750 Avenue G, SE
Kirtland Air Force Base
NM 87117-5671

Naval Aerospace Medical
Institute Library
Building 1953, Code 03L
Pensacola, FL 32508-5600

Command Surgeon
HQ USCENTCOM (CCSG)
U.S. Central Command
MacDill Air Force Base, FL 33608

Air University Library
(AUL/LSE)
Maxwell Air Force Base, AL 36112

U.S. Air Force Institute
of Technology (AFIT/LDEE)
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Wright-Patterson
Air Force Base, OH 45433

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Director, Institute of Aviation
University of Illinois-Willard Airport
Savoy, IL 61874

Chief, National Guard Bureau
ATTN: NGB-ARS
Arlington Hall Station
111 South George Mason Drive
Arlington, VA 22204-1382

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4300 Goodfellow Bouvelard
St. Louis, MO 63120-1798

U.S. Army Aviation and Troop Command
Library and Information Center Branch
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4300 Goodfellow Boulevard
St. Louis, MO 63120

Federal Aviation Administration
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P.O. Box 25082
Oklahoma City, OK 73125

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U.S. Army Institute of Surgical Research
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Fort Sam Houston, TX 78234-6200

AAMRL/HEX
Wright-Patterson
Air Force Base, OH 45433

Product Manager
Aviation Life Support Equipment
ATTN: SFAE-AV-LSE
4300 Goodfellow Boulevard
St. Louis, MO 63120-1798

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USAE Waterways Experiment Station
ATTN: CEWES-IM-MI-R,
CD Department
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Commanding Officer
Naval Biodynamics Laboratory
P.O. Box 24907
New Orleans, LA 70189-0407

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U.S. Army Field Artillery School
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Fort Sill, OK 73503-0312

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Dugway, UT 84022

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AFFTC Technical Library
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CA 93523-5000

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Naval Weapons Center
China Lake, CA 93555

Aeromechanics Laboratory
U.S. Army Research and Technical Labs
Ames Research Center, M/S 215-1
Moffett Field, CA 94035

Sixth U.S. Army
ATTN: SMA
Presidio of San Francisco, CA 94129

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U.S. Army Aeromedical Center
Fort Rucker, AL 36362

Strughold Aeromedical Library
Document Service Section
2511 Kennedy Circle
Brooks Air Force Base, TX 78235-5122

Dr. Diane Damos
Department of Human Factors
ISSM, USC
Los Angeles, CA 90089-0021

U.S. Army White Sands
Missile Range
ATTN: STEWS-IM-ST
White Sands Missile Range, NM 88002

U.S. Army Aviation Engineering
Flight Activity
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Ms. Sandra G. Hart
Ames Research Center
MS 262-3
Moffett Field, CA 94035

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Fort Detrick, Frederick, MD 21702-5009

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Fort Sam Houston, TX 78234-6000

U. S. Army Research Institute
Aviation R&D Activity
ATTN: PERI-IR
Fort Rucker, AL 36362

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U.S. Army Safety Center
Fort Rucker, AL 36362

U.S. Army Aircraft Development
Test Activity
ATTN: STEBG-MP-P
Cairns Army Air Field
Fort Rucker, AL 36362

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USAMRDALC
ATTN: SGRD-PLC (COL R. Gifford)
Fort Detrick, Frederick, MD 21702

TRADOC Aviation LO
Unit 21551, Box A-209-A
APO AE 09777

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Building 602
Fort Rucker, AL 36362

British Army Liaison Office
Building 602
Fort Rucker, AL 36362

Italian Army Liaison Office
Building 602
Fort Rucker, AL 36362

Directorate of Training Development
Building 502
Fort Rucker, AL 36362

Chief
USAHEL/USAAVNC Field Office
P. O. Box 716
Fort Rucker, AL 36362-5349

Commander, U.S. Army Aviation Center
and Fort Rucker
ATTN: ATZQ-CG
Fort Rucker, AL 36362

Chief
Test & Evaluation Coordinating Board
Cairns Army Air Field
Fort Rucker, AL 36362

Canadian Army Liaison Office
Building 602
Fort Rucker, AL 36362

German Army Liaison Office
Building 602
Fort Rucker, AL 36362

French Army Liaison Office
USAAVNC (Building 602)
Fort Rucker, AL 36362-5021

Australian Army Liaison Office
Building 602
Fort Rucker, AL 36362

Dr. Garrison Rapmund
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Bethesda, MD 20817

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Institute of Aviation Medicine
Farnborough, Hampshire GU14 6SZ UK

Defense Technical Information
Cameron Station, Building 5
Alexandra, VA 22304-6145

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and Technology Center
AIFRTA (Davis)
220 7th Street, NE
Charlottesville, VA 22901-5396

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USARTL-ATCOM
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Fort Eustis, VA 23604

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Development Test Center
101 West D Avenue, Suite 117
Eglin Air Force Base, FL 32542-5495

Aviation Medicine Clinic
TMC #22, SAAF
Fort Bragg, NC 28305

Dr. H. Dix Christensen
Bio-Medical Science Building, Room 753
Post Office Box 26901
Oklahoma City, OK 73190

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Command
Redstone Scientific Information Center
ATTN: AMSMI-RD-CS-R
/ILL Documents
Redstone Arsenal, AL 35898

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Farnborough, Hants GU14 6SZ UK

U.S. Army Research and Technology
Laboratories (AVSCOM)
Propulsion Laboratory MS 302-2
NASA Lewis Research Center
Cleveland, OH 44135

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